Engineers' Handbook of CONCRETE REINFORCEMENT

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Handbook and Catalogue

of

Concrete Reinforcement

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INTRODUCTION

IN preparing and presenting to the public this Catalogue on Reinforcement for Concrete, our effort has been to offer a book containing facts, not only regarding the reinforcement of concrete, but concrete itself. The data contained herein is not only the result of careful study of our own engineering department, but also that of some of the best known engineers of the country.

Many paragraphs and chapters dealing with reinforced concrete are selected and reprinted by permission, from "Concrete Plain and Reinforced," by Taylor & Thompson; "Reinforced Concrete", by Buel & Hill, and others.

We are presenting two distinct designs or types of Steel Wire Reinforcement—Triangular and Square Mesh. Our Triangular Mesh is built up of either stranded or solid longitudinal or tension members, with the cross or bond wires arranged or running diagonally across the widths of fabric. This arrangement not only affords the most even distribution of the steel, reinforces in every possible direction, and provides the most ideal mechanical, as well as adhesive bond between the steel and concrete. Tables of weights, areas, bending moments and Tensil strengths of this Triangular Reinforcement are shown on Pages 76, 77, 78, 79.

Our Square Mesh type of reinforcement is similar to that made by other manufacturers of this style, the longitudinal or tension members being solid or single wires—evenly spaced, one from the other—with the cross or bond wires running at right angles with the tension members. This style being also an excellent reinforcement for concrete. Tables of weights, areas, etc., of this Square Mesh are shown on Pages 80, 81.

Tables are given showing the weight per square foot, number, sizes, spacings, and areas of wires and longitudinal strands; also, tables and diagrams giving moments for usual thickness of slabs, by the aid of which a suitable fabric, used with or without bars, may be selected for all kinds of loads, spans, and conditions met with in the construction of buildings, bridges, and reinforced concrete in general.

It may be found that two or more fabrics will have an area corresponding to the required bending moment. In this case, the comparative listed price, weight per square foot, and the design of the building must decide which is the most efficient type.

The formula used in calculating the table of moments is based on the tests made by A. N. Talbot, reported in the proceedings of the American Society for Testing Materials. These we believe to be the most reliable and complete tests, involving no theoretical assumptions.

We feel that the tables of strengths we are offering are the best, and are perfectly safe and reliable.

Having adopted a working stress of 16,000 pounds per square inch, which is allowed by the buildings laws of most large cities. This is about one-quarter of the strength of ordinary mild steel wire, and if our formulas and tables are used, the concrete will not be strained so as to cause cracks in the tension side, if reinforcement and concrete are properly placed and selected.

While we recommend the use of our ordinary mild steel fabric such as covered by our tables, there are cases when a structure may be subjected to uncertain and fluctuating loads which may cause cracks in the concrete. In such cases, we recommend fabric made of wire having a much higher tensile strength.

We can furnish fabric composed of steel wire having a tensile strength of two or three times that of the steel specified in the tables, the elastic limit of which may reach as high as 120,000 pounds. With a factor of safety of 4, we can therefore allow stress of 30,000 pounds per square inch, instead of 16,000 pounds. In fact, we are prepared to furnish any grade of steel desired; this because the amount of carbon or the hardness of the steel does not interfere with the proper construction of our fabric.

In our tables we have assumed an average composition of concrete, using high grade Portland cement in the proportion of 1, 2-½, and 5. This we have found to be an average composition of all concrete, which has given the best results, and which may be recommended for all floors or other structures subjected to high stresses.

In both our Triangular and Square types, we can make the longitudinal members of either single wires or strands. Although we believe that there is actually no slipping possible between the steel and the concrete, and that our single-wire types meet all possible conditions for ordinary loads and spans, we find that the twisted longitudinal strands embody all the features and advantages claimed for the twisted or corrugated bar systems. Besides, a strand exposes more surface in relation to the area for the adhesion to the concrete, which we believe is a decided advantage as well as a most perfect mechanical bond.

Fully convinced that our Triangular type is far superior to any metal reinforcement heretofore used, we wish to call attention to the special features. It is impossible for the cross wires to slip without breaking, and our method of making the joint between the continuous cross wire and the longitudinals makes this type especially desirable for such constructions which are subjected to great variations in temperature, or to prevent cracks due to shrinkage in concrete covering large areas. It has all the desirable features of the expanded metal, but of course, represents an entirely different article when strength is

considered. This is owing to the straight continuous longitudinals which take the main portion of the load, and can be made with almost any desired capacity. Another advantage is that in breaking concrete reinforced by our Triangular Reinforcement, the diagonal cross wires must also be sheared or pulled apart; hence, they add to the strength of the reinforcement, which is not the case with a square mesh.

REINFORCED CONCRETE.

The uses of reinforced concrete are daily increasing. Results are being obtained with this material which are not only more practical, but more economical than that of materials previously employed. As a fire proofing it has no equal. The article below "How Good is Concrete," by Walter Loring Webb, C. E., reprinted by permission from the March issue of the Technical World Magazine, Chicago, is one of the best illustrations of its uses and value, and cannot be overlooked, coming from one having so wide experience with concrete:

HOW GOOD IS CONCRETE?

A building material that will not rust or decay and that will not be subject to the attacks either of insects or of atmospheric acids; that will be fireproof and earthquake-proof and capable of supporting heavy loads over long spans—a material that has all these virtues and still is not prohibitively costly—such a material would be close to ideal. And the material that most nearly meets these essential requirements and that is daily undergoing tests with credit is reinforced concrete.

The usual building materials fall far short of the above ideal. Wood, in spite of its many advantages, is subject to decay and the ravages of the *teredo navalis* if it is placed in seawater; it must be frequently repainted and it is highly combustible. Steel, in spite of constant repainting, will rust unless it is thoroughly protected by concrete. Unless it is thoroughly fireproofed, the heat usually developed by a conflagration is so great that the steel will soften and yield, thus causing the whole structure to collapse. Although stone in the form of building blocks has the great advantage of architectural beauty, it cannot withstand fire and especially the frequent combination of the great heat of a conflagration and the sudden application of a stream of cold water. The carbonic acid of the atmosphere will speedily affect marble and limestone fronts. Stone is useless for long spans except in the form of expensive arches which must have a considerable rise in proportion to the span and this renders its use inapplicable for all except a limited class of expensive structures. The recent destruction of San Francisco by Earthquake shows how helpless the ordinary stone or brick structure is under such circumstances. Brick has nearly all of the disadvantages of stone except in degree. A good quality of brick will withstand fire far better than stone, and is unaffected by frost or the carbonic acid in the atmosphere, but its use is absolutely limited to supplying compressive resistance.

The very expensive method of floor construction, using steel I-beams with small arches of brick or hollow tile, which a few years ago was considered to be the only method which deserved the name of fireproof, has been found to be only relatively fireproof and in fact it affords but little protection against a hot fire. It was one of the

compensations of the Baltimore fire that it furnished a very convincing test of the relative methods of the various systems of fireproofing which have been devised. The old-fashioned floors constructed of steel I-beams, connected by brick or by hollow tiles, provided little or no protection to a building against its almost complete destruction by the flames. On the other hand, the few existing floors of reinforced concrete were structurally unharmed during that trial.

In strong comparison with the qualities of the various building materials enumerated above is the statement of the corresponding qualities of reinforced concrete. It is in no sense subject to decay and when it is used in seawater for the foundation of a pier or wharf it is unaffected by the *teredo*, which so quickly destroys timber. It is not affected by rust nor by the carbonic acid in the atmosphere. When properly constructed, it requires no maintenance charge for painting or for any other kind of protective treatment. The various tests, which have been made by the building bureaus of great cities, as well as by the involuntary test of great conflagrations, have shown that its power for resisting fire—and even a combination of fire and water—is greater than that of any other known type of building construction. Although the lower layer of concrete will probably be calcined during a fire, the lower layer will of itself act as a fire-proofing material which will prevent injury to the upper layers. Since the area of the lower layer is always regarded in computing the strength of the reinforced concrete, it is always possible after such a fire to scrape off the injured concrete and to replace it with a layer of other material which will again act as a fire-proofing material. Structurally the floor will be uninjured. A brief description of one of these tests will show the remarkable resistance of reinforced concrete to fire.

During November, 1905, a building was constructed near New Brunswick, New Jersey, for the special purpose of the test. The roof consisted of a four-inch slab of reinforced concrete supported on concrete beams. The side walls of the building were made of concrete. A grate of iron bars was built across the entire floor area and ample provision was made for draft. When the concrete had become sufficiently hard, the roof was loaded with a dead load of pig iron to the amount of 150 pounds per square foot. On December twenty-sixth, the structure was tested. A fire was built and fed with cordwood until an electric pyrometer indicated a temperature of 1,700° F. This temperature, with small flunctuations above and below, was maintained for four hours. Then the firedoors were opened and a stream of water, having a pressure of ninety pounds per square inch at the pumps was played on the under surface of the roof for ten minutes. As was expected, the lower layer of concrete, which had been calcined by the heat, was swept off by the mechanical action of the powerful stream, but the roof still held its load of pig iron. On the following day, the concrete having cooled off and having recovered a large part of its deflection during the fire, still more pig iron was loaded on until the load amounted to 600 pounds per square foot, and even at such a

load, the four inch slab, which had been subjected to such a severe alternation of intense heat and rapid cooling, was not broken down. The one fact that the structure was sufficiently elastic to recover, while cooling, a large proportion of its deflection during the intense heat shows a very remarkable quality of this material.

There was also a compensation in the San Francisco disaster when it was demonstrated that the few instances of reinforced concrete work which were located within the area of the disturbance were structurally uninjured by the earthquake. The monolithic character of these buildings prevented their disintegration when adjoining buildings, consisting of brick and stone joined by mortar joints having little cohesive strength, were rapidly disintegrated by the earthquake shocks. Owing to the limitations of the building laws there were no buildings in San Francisco itself which were constructed entirely of reinforced concrete, although there were many floors of this material. An official inspection of all injured buildings was made by an expert for the Board of Underwriters. His report on the injury to reinforced concrete floors was almost monotonously "no structural damage." The very few cases of reported injury were invariably accompanied by the statement that the supports of the flooring had given away.

Perhaps the most remarkable characteristics of reinforced concrete construction is the fact that girders, beams and floor slabs, having a very considerable span and comparatively little vertical depth, may be built so as to carry the heaviest working loads desired by modern conditions. This characteristic only becomes possible on account of its power of resistance to transverse bending. Such resistance depends on the ability of the material to resist tensile stresses . This tensile strength is furnished by the steel which is so proportioned and placed that it will furnish the desired resistance . It is not very many years since an engineer would have been considered foolish to have predicted that two such dissimilar materials as concrete and steel could be combined into a composite structure and that they would mutually reinforce each other and each supply the qualities the other lacked. The tensile strength of concrete is usually very small. Although some specimens have required a pull of 300 or 400 pounds per square inch and even more to break them, the breaking strength is usually not more than 200 pounds per square inch, which is so small that it becomes practically useless to depend on such strength for transverse stresses of any magnitude. It may be easily demonstrated by practice as well as by theory that a concrete beam, whose span compared with its depth is comparatively large, will not even support its own weight, to say nothing of carrying a live load. It is not considered safe practice to depend on a working tensile stress of more than 50 pounds per square inch in concrete. On the other hand, even a low-carbon steel will usually have an ultimate tensile strength of 55,000 to 60,000 pounds per square inch and a high-carbon steel, such as is frequently used in reinforced concrete, has an ultimate tensile strength of about 100,000 pounds per square inch. Even if we only allow a working

stress of 16,000 pounds per square inch in the steel, we are using a working stress which is 320 times as great as that which is permissible in the concrete. A cubic foot of steel weighs about 490 pounds. At three cents per pound this is worth $14.70. On the other hand, a cubic foot of concrete is worth perhaps 20 cents or, let us say, 1-75th of the cost of steel. But if the steel is 320 times as strong as the concrete we can afford to pay 75 times as much for the unit area of steel as for the unit area of concrete and even then the steel is more than four times as cheap as the concrete, considering what it will accomplish. On the other hand, with a good grade of concrete we may safely use a working stress of 500 pounds per square inch in compression. We cannot safely use more than 16,000 pounds per square inch as the working tension for steel. This is only 32 times the allowable working stress in the concrete, and since the steel costs about 75 times as much as the concrete, the concrete is far cheaper as a material with which to withstand compression. It should be realized that the real test is the actual cost of obtaining so many pounds of tension or compression, almost regardless of the kind of material which furnishes it. Although the above unit values of concrete and steel may be varied, both actually and relatively, they are substantially correct and will never be modified so greatly as to alter the general conclusion that by constructing our beams and slabs by such a method that the tension is furnished by steel and the compression by concrete, we have the most economical combination of materials.

Of course there is far more to the theory of reinforced concrete than the mere placing of steel in the tension side of a beam or slab. Every ounce of tension in the steel is only effective as it is transferred to the concrete. In the case of a plain beam with free ends, there is no stress in the steel at the ends while the maximum tension is usually at or near the center of the beam. The entire amount of this tension must be gradually transferred from the steel to the concrete. In the earlier designs the adhension of the concrete to the steel was relied on to permit the transfer of this stress from one material to the other. Elaborate tests have been made to determine the amount of this adhesion. Although the experimental values vary, as was to be expected, there was sufficient uniformity apparently to indicate a fairly constant safe working value. A great deal of reinforced concrete work has been done—and is still being done—on the basis of the permanency of this adhesion. But it is now being realized that this adhesion is not permanent and that, regardless of its value in comparatively new and fresh test specimens, the adhesion is very greatly reduced with age and under certain unfavorable conditions, such as continued soaking of the concrete in water, long continued vibration, etc. Failures of floors have already occurred, due to loss of the adhesion after they have successfully supported heavy loads for many years. On this account "deformed" bars, which have an irregular surface and which furnish a "mechanical bond" are now being extensively and even exclusively

employed by many engineers. Some of these bars require to pull them out of concrete more than twice the force that is required by plain bars of the same cross-section. This shows that even if the adhesion were entirely destroyed, the mechanical bond will still furnish as much resistance to slipping as will be furnished by adhesion alone under the most favorable circumstances. Such a union between the concrete and steel at all points along its length in an absolute essential to the stability of such structure.

It is said that a florist first conceived the idea of combining metal and cement, in making flower pots. He found that they could be made more tough and less liable to break by imbedding wire netting in the concrete. The success of these flower pots encouraged the extension of the principle of combining steel and concrete.

One of the most economical applications of reinforced concrete lies in the construction of retaining walls. Although there is some variability and uncertainty as to the amount of the actual lateral pressure of earthwork, the proper design of solid masonry retaining wall becomes an exact problem when we have once assumed the direction, point of application and amount of the earth pressure. This usually requires a very large cross section of masonry, which is correspondingly expensive. The reinforced concrete method employes a comparatively thin vertical curtain wall and a large base plate which is as wide and perhaps a little wider than the ordinary plain retaining wall, the base plate being tied to the thin face wall by buttresses spaced at frequent intervals. The face wall and base plate are both capable of withstanding transverse stresses, while the stress in the buttresses is usually that of tension. Since reinforced concrete is the one form of masonry which can withstand any considerable amount of transverse and tensile stresses, the above form of construction can only be made in reinforced concrete. Of course, the same form could be adopted if we used steel or wood, but the durability of either material would be so little that it would not pay to construct a retaining wall of such materials.

Another remarkable application of reinforced concrete is the possibility of making columns which are much stronger than plain concrete columns and yet which do not employ a core of steel to take the most of the compression. A column whose length is 20 or 25 times its diameter will probably fail by buckling, in which case the steel on the convex side of the column would be subject to tension rather than compression. But a "short" column must fail by compression, if subjected to sufficient stress. Even in this case, steel may be employed to furnish strength on account of its resistence to tension. Although the explanation is not theoretically exact, the principle mighth be explained by an illustration of filling a stove pipe with sand and subjecting it to compression. The sand alone, especially if dried, would not sustain its own weight as a column. When confined by the stove pipe the compression of the sand will cause a bursting pressure on the pipe. If the pipe were filled with a liquid instead of sand and if a piston,

which fitted the pipe tightly, were placed on top of the liquid so that a load could be placed on the piston, the resulting bursting pressure on the pipe would be a perfectly definite mathematical quantity depending on the load which was placed on the piston and also on the weight of the liquid. When we use sand instead of the liquid, the grains of sand will tend to lock themselves together and the load on the sand would need to be proportionately far greater to produce any given tension in the pipe. Using concrete instead of sand the resistance to the "flow" of the material will be still greater, which practically means that a comparatively small amount of tensile strength in the pipe will produce a very much added resistance to compression. In practice, instead of using an actual pipe of metal, a series of rings are made of light bars and spaced a few inches apart are bent around a few longitudinal bars whose chief function is to form a framework on which to fasten the horizontal rings and prevent them from becoming displaced during the laying and tamping of the concrete. Such compression members are used not only for vertical columns, but also as the compression members of truss bridges, of which several have been constructed. Tests of such columns have required a compression of over 6,000 pounds per square inch to cause failure. Although the construction of trussed forms in reinfroced concrete is not common, the reinforcement of vertical columns in such a manner that they may be safely subjected to greater loads than should be placed on plain concrete columns of equal size, is now recognized as safe engineering practice.

Another useful application of reinforced concrete lies in the building of structures which are especially subject to the fumes arising from the stacks of locomotives. This applies not only to engine houses and coaling stations, but also to over-head highway bridges, which cross railroads The concentrated gases of combustion have a corrosive action on steel which wears it away in the course of a few years. No matter how much the steel may be protected by paint, even the paint will be worn off by the mechanical action of the fine cinders which are blown out by the exhaust and which act as a very effective form of sand blast. Probably most kinds of paints are chemically affected more or less but the combination of chemical action and mechanical wear will destroy any protective covering in a comparatively short time. Reinforced concrete is absolutely unaffected chemically while the mechanical sand-blast action of the exhaust is so utterly insignificant that it need not be considered. Although a wooden structure is not seriously affected by the exhaust, its lack of durability, its danger from destruction by fire and the recent very great increase in the price of lumber, have combined to render wood an unsatisfacbtory and un economical material for such structures.

The advantages of reinforced concrete in the construction of coaling stations also is now being recognized. A frame work of structural steel, with steel plates for the floors and sides of the pockets, has been tried in order to obtain a non-combustible structure. But the sulphuric acid, always present in the coal, corrodes the steel very rapidly and the

life of such a structure is short. If the steel is adequately protected against corrosion by concrete, the cost is considerably in excess of a steel structure, but far greater permanence is secured.

In its application to the construction of masonry dams, reinforced concrete has entered another field. A solid masonry dam is usually constructed on the gravity principle, which means practically that the volume of its masonry is so great and so heavy that it is supposed to be safe against over-turning, but the cost of such a construction is so great that the cross section of the dam is usually reduced to the lowest limit which is considered permissible. The upper face of such a dam usually makes an angle considerably greater than 45° with the horizontal and, under such conditions, a flood over the dam will raise the line of pressure and decrease the factor of safety. The higher the flood, the greater the danger. Under such conditions, a weakening of the foundation or an unsuspected washing out of the sub-soil may cause a settlement and a shifting of the line of pressure until the factor of safety, which for the sake of "economy" has been made very low, is wiped out and the result is a disaster which perhaps spreads destruction through a valley.

Another type of dam is illustrated in an old fashioned timber dam which is always constructed with a comparatively flat up-stream face, the angle of the upper face with the horizontal being less than 45°. Even the line of the resulting water pressure lies inside the base of the dam. There is never any tendency to over-turn and a flood only increases the pressure of the dam on its foundation. As long as such a dam is kept tight, so that there is no flow of water through the dam to disintegrate the foundation, the dam is usually safe, but, being constructed of timber which is usually alternatly wet or dry, the life of such a dam is exceedingly limited, and, considering the present price of lumber, is not even economical.

A reinforced concrete hollow dam combines all of the safe principles and advantages of a timber dam with the indefinite durability of first class masonry construction. The up-stream face of a concrete dam is made with a comparatively flat slope, usually less than 45° with the horizontal. Hydraulic pressure being a perfectly definite quantity, it enables the engineer to design such a dam with a full knowledge of the stresses to which it will be subjected. These stresses are such that they may be easily provided for by the skeleton construction which is adopted for these dams. The dams consist essentially of an up-stream "deck" whose chief duty is to withstand the direct and definite pressure of the water above it. This deck is supported at intervals by vertical walls which are parallel with the line of the stream and which transfer the pressure to the foundation of the dam. One great advantage in the method of construction is that, the dam being hollow, it is possible to detect any leaks which might develop and usually they can even be repaired without emptying the reservoir. The broad base of these dams permit them to be placed on sub-soils which ordinarily would be considered too soft for any masonry dam,

but which can sustain on such a broad base all the pressure which can possibly come on them.

Concrete dams are constructed very rapidly and at such a reduction of cost below that of ordinary masonry dams that such designs have rendered practicable the utilization of water powers which would not financially justify the construction of an ordinary stone masonry dam. The construction of these hollow concrete dams has even permitted the utilization of the space within them for gates and even for the location of water wheels and dynamos, thus permitting a very great reduction in the cost of the entire plant. Such a dam may even contain a passageway which will permit crossing the river in times of the highest floods, and thus save the construction of a bridge at that point. The dam recently constructed at Schuylerville, New York, is an illustration of this feature.

Another remarkable characteristic of reinforced concrete construction is the possibility of avoiding expansion joints in continuous structures, no matter what may be the length. For example, if it were desired to construct a retaining wall with a length of a mile or more it can be done without employing expansion joints such as would be absolutely necessary with any other form of masonry construction. Many engineers are still skeptical on this point but the ultimate proof of such a theory lies in practice and it is indisputable that there are many examples of structures built of reinforced concrete which would unquestionably have shown temperature cracks if they had been built of ordinary masonry, but which, although built for several years—long enough for such cracks to have developed—have not shown any evidence of cracking.

The only apparent rational explanation of what appears now to be an undoubted fact is, practically, the same as that which permits a reinforced concrete beam to be deflected for a very considerable percentage of its span without showing any cracks on the stretched side. It is well-known that plain concrete cannot be stretched more than a very minute fraction of its length without cracking. A very long monolith of plain concrete will nearly always develop cracks which are caused by a concentration of the stretching at the weakest points in the concrete and since the proportional amount at which concrete may be stretched without rupture is very small, a concentration of the extension at one place will cause rupture at that point. If the metal is properly imbedded in the concrete, so that the concrete and the metal will stretch together, then the deformity of the concrete by stretching will be distributed uniformly throughout its length instead of being confined to a few points.

Objection is sometimes made to the policy of not using expanded joints on the ground that there have been several instances of monolithic reinforced concrete structures in which temperature cracks have developed. In such cases it is easily demonstrable that the metal was not well distributed through the body of the concrete. The effectual prevention of cracks is only accomplished by such an intimate union of

the concrete and the steel that they must act together under all circumstances and conditions of temperature. It is not an easy matter to compute theoretically just what proportion of metal will be needed to insure a wall against cracking. It is probably true that the metal which will ordinarily be needed for reinforcement will also be able to take care of such stresses and it is certainly true that the uniform distribution of the metal is of far greater importance than its amount. The Harvard stadium has a length of fourteen hundred feet and was constructed without expansion joints. It has already experienced three northern winters. No cracks have developed in this structure except at a point where the straight portion joins the semi-circular end and even here the cause of the crack is not considered due to changes of temperature.

Reinforced concrete has even invaded the realm in which stone masonry has been considered from ancient times the best building material and is now strongly competing with it in the construction of arch bridges both because it is cheaper and also better. Stone arch bridges have been built for many hundreds of years. Some of them have been built by men who probably had no knowledge of the theoretical mechanical principles now used in designing such arches. And yet these men constructed arches of long span which had comparatively little rise. But since the stone arch depends purely on compressive stresses the design has very definite limitations. It is almost invariably found that the dead weight of a stone arch is several times the maximum live load may be safely placed on it and that even a portion of this load if placed near one end of the arch, may test it more severely than the full load uniformly distributed. The ability of a reïnforced concrete arch to withstand transverse stresses furnishes a large element of safety which is wholly unobtainable with plain stone masonry and actually permits dimensions and proportions which would be unsafe in a stone arch.

Although a reinforced concrete arch is usually designed so that the "line of pressure" for full loading will pass nearly through the center of the arch which means that every portion of the arch is under compression, yet the arch will not necessarily fail if, for an eccentric loading, the line of pressures should pass entirely outside of the arch ring. In such a case, its stability would depend on the transverse strength of the arch section. A plain stone arch with the same dimensions and loaded in the same way would necessarily fail. Reinforced concrete is superior for such a purpose.

In dealing further with the uses and properties of reinforced concrete, we reprint, by permission, Chapter I, from "Reinforced Concrete," by Buel & Hill:

CHAPTER I.—ECONOMIC USE AND PROPERTIES OF REINFORCED CONCRETE.

Concrete alone, considered as a building material, is nothing more nor less than a kind of masonry. The distinguishing features between rubble masonry and concrete are really confined to the methods of mixing and placing the materials. The results obtained with rubble masonry made of very small stone and with concrete made of large stone would be practically identical . The old Roman concrete was made with large stones, and may be classified either with rubble or concrete masonry. The value of either rubble or concrete as a material for construction depends largely on the quality of the cement used and the care exercised in the mixing and placing. Examples of masonry structures composed of large stones reinforced or tied together with iron rods and bars are found in the works of all periods, but usually only in connection with cut-stone masonry. The cost of such reinforcement was very great compared with the additional strength secured, and with rubble masonry the mechanical difficulties involved and the comparative cost render it impracticable.

Reinforced Concrete..—With the advent of modern concrete the facilities with which reinforcing rods or bars of metal may be embedded anywhere in the mass of the masonry was soon seen and taken advantage of. The compressive resistance of concrete is about ten times its tensile resistance, while steel has about the same strength in tension as in compression. Volume for volume steel costs about fifty times as much as concrete. For the same sectional areas steel will support in compression thirty times more load than concrete, and in tension three hundred times the load that concrete will carry. Therefore, for duty under compression only, concrete will carry a given load at six-tenths of the cost required to support it with steel. On the other hand, to support a given load by concrete in tension would cost about six times as much as to support it with steel. These economic ratios are the *raison d'etre* of reinforced concrete . If the various members of a structure are so designed that all of the compressive stresses are resisted by concrete and steel is introduced to resist the tensile stresses, each material will be serving the purpose for which it is the cheapest and best adapted and one of the prinçiples of economic design will be fulfilled.

Other important advantages secured in the combination of concrete and embedded steel are that the protection of the metal elements from corrosion is practically perfect; that, with properly selected ingredients, the fire and heat resisting qualities are very high, perhaps surpassed by no other building material except fire-brick; and, in many

cases, that the substantial appearance of a masonry structure is obtained at about the cost of a more or less temporary unprotected steel structure. When intelligently reinforced with steel, concrete becomes a material suitable and economical for beams, floors, and long columns, tanks, reservoirs, conduits, and sewers; admirably adapted to arch construction, and often economical for dams and retaining-walls. Even in concrete that is not subjected to tension or flexure it is often desirable to introduce steel reinforcement to prevent the occurrence of cracks due to shock or settlement, or other causes.

Properties of Concrete.—A knowledge of the properties of materials is the first requisite for safe and economic designing of structures. The properties of reinforced concrete comprise not only those of the concrete and of the steel elements considered separately, but may be said to include those properties or characteristics of the composite mass that control the distribution of stresses between the elements of the combination of units and determine the nature of their interrelation. Such properties as are required by the practical engineer or architect in intelligent designing are here assembled in concise form, with values assigned to them that are considered to be safe and conservative deductions from the most recent experiments accessible. The scope and purpose of this work does not permit of an elaborate exposition of all the recent experiments nor of an exhaustive discussion of the deductions to be drawn therefrom.

Portland-cement concretes only will be considered. Concrete made with natural slag, or Puzzolanic cements, although adapted to many uses, do not possess the qualities desirable for reinforced concrete structures, and all the experiments known to the writer, on which the theories of reinforced concrete are based, have been with Portland-cement concretes. The object of reinforcing concrete with steel is to secure greater strength or safety, or both, than can be attained with concrete alone; and excepting a few special cases where the concrete is used principally for a filling or to add mass to the construction, concrete made with Portland cement will generally be found the most economical for equal strength, safety and durability.

The properties of concretes vary with their age and with the proportions and quality of the ingredients. The values given here are for concretes made with (1) true Portland cement having a tensile strength per square inch neat, in 7 days of 450 to 650 lbs., and in 28 days of 540 to 750 lbs.; (2) silica sand, not necessarily sharp nor coarse, but absolutely clean, and preferably a mixture of fine and coarse; and (3) good, hard, screened broken stone or clean gravel. The proportions of cement to sand generally used in the mortar or matrix, and for which there are reliable experimental data, vary from 1 of cement to 1 of sand up to 1 of cement and 6 of sand; and the proportion of mortar or matrix to the aggregate (broken stone or gravel) is from 100 to 110 per cent of the voids of the latter.

This method of specifying the proportions, by cement to sand in the mortar or matrix and by mortar or matrix to voids in the aggregate,

is here adopted because it is believed that the ratio of matrix to aggregate, where the latter is good clean material, does not affect the strength of the concrete, except in so far as sufficient matrix should be provided to fill the voids in the aggregate. Other things being equal, the strength of the concrete will be proportional to the strength of the mortar, and the maximum strength for a given matrix or mortar will be attained when all voids are filled . In practice this requires a volume of matrix about 10 per cent. in excess of the voids in the aggregate. Thus, if by mixing several sizes of broken stone or gravel, the proportion of voids to be filled is reduced from 45 per cent. or 50 per cent. down to 30 per cent., the proportion of matrix, cement and sand, to aggregate may be considerably reduced without reducing the strength of the concrete or affecting its properties. Where cement or sand are dear and stone and gravel are cheap advantage may be taken of this method to reduce the cost of the concrete very materially.

The values here given are for concretes seven days, and one, three, and six months old. Those values should be used which correspond to the age at which the structure may be subject to its full load.

Compressive Strength.—Concrete is more often used in compression than in any other way, since it is more economical and has heretofore been considered more reliable under compressive strains than under transverse or tensile strains. Until very recent years engineers and architects hardly gave serious consideration to the value of concrete as a material to resist bending or tensile stresses, but at the present time comparatively few hesitate to use it in beams and similar situations where it is partly subjected to tensile stress, and considerable number of eminent members of both professions have constructed works where the tensile strength of the concrete is taken advantage of. The best practice, where any tensile strains can occur, is to reinforce the section with steel. The two chief factors that determine the compressive strength of a concrete are its age and the proportion of sand to cement in the matrix. The quality of the cement, sand, and aggregate have more or less influence on the resulting concrete, but with any good brand of modern high-burned Portland cement, clean sand, and clean, hard stone, substantially the same results may be secured. Factors of far greater weight are the manner and conditions of mixing and placing, and the personal equation of the operator. On this account it is extremely difficult to harmonize or draw conclusions from the large number of isolated tests that have been made by independent investigators under widely varying conditions and often with different objects in view.

A set of experiments made at the Watertown Arsenal for Mr. George A. Kimball, Chief Engineer of the Boston Elevated R. R., in 1899, are the most homogeneous and systematic set of tests that have as yet been published, and are given in Table I.

From these tests Mr. Edwin Thatcher has deduced formulas for the ultimate strength of concretes. They give results that agree with

the average of the experiments and can be entirely relied upon for concretes carefully made from good materials. They are as follows: The ultimate compressive strength in pounds per square inch of concrete:

$$7 \text{ days old} = 1{,}800 - 200 \left(\frac{\text{volume of sand}}{\text{volume of cement}}\right),$$
$$1 \text{ month old} = 3{,}100 - 350 \left(\text{do.}\right),$$
$$3 \text{ months old} = 3{,}820 - 460 \left(\text{do.}\right),$$
$$6 \text{ months old} = 4{,}900 - 600 \left(\text{do.}\right),$$

These formulas give the results shown in Table II.

Tensile Strength.—The tensile strength may be safely placed at one-tenth of the compressive strength, and the modulous of transverse rupture, $f=\frac{M}{S}$ at about $1\frac{6}{10}$ that of the tensile strength. Tetmajer gives the ratio as follows for Portland-cement mortars consisting of 1 of cement to 3 of sand by weight:

$$\text{Tensile strength} = \left(\frac{\text{compressive strength}}{8.64+1.8 \text{ log. of age in months}}\right).$$

Shearing Strength.—M. Mesnagen states that the shearing strength of concrete is from 1.2 to 1.3 times the tensile strength. Bauschinger gives the shearing strength of concrete four weeks old at 1.25 times the tensile strength, and at two years old 1.5 times the tensile strength. A paper on the "Shearing Resistance of Reinforced Concrete," by S. Zipkes, translated by Mr. Leon S. Moisseiff, in "Cement," for March, 1906, gives the average shearing strength, at the appearance of the first cracks, at 81 lbs. per square inch. At the time of rupture, he found the average to be 357 lbs. per square inch. Prof. Moersch ("Cement", July, 1893) obtained an average shearing resistance of 400 to 440 lbs. per square inch. Prof. Moersch's beams were tested at three months old, whereas Mr. Zipkes' specimens were all tested at an age of 50 days. Considering the difference in the age of the specimens, the agreement is fair.

TABLE I. — SHOWING COMPRESSIVE STRENGTH OF CONCRETE AS DETERMINED BY TESTS MADE AT WATERTOWN ARSENAL IN 1899.

MIXTURE 1 : 2 : 4.

Brand of Cement.	Compressive Strength, Pounds per Square Inch.			
	7 Days.	1 Month.	3 Months	6 Months.
Atlas	1,387	2,428	2,966	3,953
Alpha	904	2,420	3,123	4,411
Germania	2,219	2,642	3,082	3,643
Alsen	1,592	2,269	2,608	3,612
Average	1,525	2,440	2,944	3,904

MIXTURE 1 : 3 : 6.

Brand of Cement.	Compressive Strength, Pounds per Square Inch.			
	7 Days.	1 Month.	3 Months.	6 Months.
Atlas	1,050	1,816	2,538	3,170
Alpha	892	2,120	2,355	2,750
Germania	1,550	2,174	2,486	2,930
Alsen	1,438	2,114	2,349	3,026
Average	1,232	2,063	2,432	2,969

MIXTURE 1 : 6 : 12.

Brand of Cement.	Compressive Strength, Pounds per Square Inch.			
	7 Days.	1 Month.	3 Months.	6 Months.
Atlas	594	1,090	1,201	1,583
Alpha	564	1,218	1,257	1,532
Germania	759	987	963	815
Alsen	417	873	844	1,323
Average	583	1,042	1,066	1,313

TABLE II.—SHOWING ULTIMATE COMPRESSIVE STRENGTH OF CONCRETE AS DETERMINED BY THACHER'S FORMULAS.

Mixture.	Age.			
	7 Days.	1 Month.	3 Months.	6 Months.
1:1 :3	1,600	2,750	3,360	4,300
1:2 :4	1,400	2,400	2,900	3,700
1:2½:5	1,300	2,225	2,670	3,400
1:3 :6	1,200	2,050	2,440	3,100
1:3½:7	1,100	1,875	2,210	2,800
1:4 :8	1,000	1,700	1,980	2,500
1:5 :10	800	1,350	1,520	1,900
1:6 :12	600	1,000	1,060	1,300

TABLE III.—SHOWING MODULUS OF ELASTICITY OF CONCRETE AS DETERMINED BY TESTS AT WATERTOWN ARSENAL IN 1899.

MIXTURE 1 : 2 : 4.

Brand of Cement.	Modulus of Elasticity between Loads of 100 to 600.			
	7 Days.	1 Month.	3 Months.	6 Months.
Atlas	2,778,000	3,125,000	4,167,000	3,125,000
Alpha	....	2,083,000	4,167,000	3,125,000
Germania	2,500,000	....	3,571,000	4,167,000
Alsen	2,500,000	2,778,000	2,778,000	4,167,000
Average	2,592,000	2,662,000	3,670,000	3,646,000

MIXTURE 1 : 3 : 6.

Brand of Cement.	Modulus of Elasticity between Loads of 100 to 600.			
	7 Days.	1 Month.	3 Months.	6 Months.
Atlas	1,677,000	3,125,000	2,778,000	3,571,000
Alpha	....	2,083,000	3,571,000	4,167,000
Germania	2,273,000	2,273,000	2,778,000	3,125,000
Alsen	1,667,000	2,273,000	2,778,000	3,571,000
Average	1,869,000	2,438,000	2,976,000	3,608,000

MIXTURE 1 : 6 : 12.

Brand of Cement.	Modulus of Elasticity between Loads of 100 to 600.			
	7 Days.	1 Month.	3 Months.	6 Months.
Atlas	....	1,316,000	1,136,000	1,786,000
Alpha	....	1,667,000	1,786,000	1,923,000
Germania	....	961,000	2,083,000	1,786,000
Alsen	....	1,562,000	1,562,000	1,786,000
Average	....	1,376,000	1,642,000	1,820,000

Modulus of Elasticity.—It has been said that no property of materials of construction is as uniform and reliable as the modulus of elasticity. This may be true of the modulus of elasticity of concrete, but the great variation in its value, as determined by the experiments heretofore published, has left the matter very much in the dark. Its value has been stated all the way from 750,000 to 5,000,000. This has been a discouraging condition for conservative constructors, and, no doubt, has greatly retarded the introduction of reinforced concrete in important works. The Watertown Arsenal tests in 1899 give values for the modulus of elasticity E of concrete as shown in Table III.

From Table III the following formulas have been deduced, giving values very close to the averages of the experiments and sufficiently exact for all practical purposes. For concrete:

7 days old, $E=2{,}600{,}000-700{,}000\left(\frac{\text{volume of sand}}{\text{volume of cement}}\right)-2,$

1 month old, $E=2{,}900{,}000-300{,}000$ (do. —1),

3 months old, $E=3{,}600{,}000-500{,}000$ (do. —2),

6 months old, $E=3{,}600{,}000-600{,}000$ (do. —3),

If the term $\left(\frac{\text{volume of sand}}{\text{volume of cement}}-c\right)$ is zero or less than zero (negative), the entire term is to be considered zero. In other words, all negative values must be considered as zero. Table IV shows the moduli of elasticity as determined by the above formulas. These values are sufficiently reliable for all ordinary purposes, and are probably as

near to the truth as any that can be deduced from the experiments at present available. A large number of carefully executed experiments will be required to determine these values with greater precision.

TABLE IV.—SHOWING MODULI OF ELASTICITY OF CONCRETE AS DETERMINED BY FORMULAS.

Mixture.	Age.			
	7 Days.	1 Month.	3 Months.	6 Months.
1:1 :3	2,600,000	2,900,000	3,600,000	3,600,000
1:2 :4	2,600,000	2,600,000	3,600,000	3,600,000
1:2½:5	2,250,000	2,450,000	3,350,000	3,600,000
1:3 :6	1,900,000	2,300,000	3,100,000	3,360,000
1:3½:7	1,550,000	2,150,000	2,850,000	3,300,000
1:4 :8	1,200,000	2,000,000	2,600,000	3,000,000
1:5 :10	500,000	1,700,000	2,100,000	2,400,000
1:6 :12	....	1,400,000	1,600,000	1,800,000

Mr. W. H. Henby has given forty-eight determinations of the modulus of elasticity under tensile stress and eighteen under compressive stress, but the conditions were varied so that they can only be compared in groups of two or three tests with constant conditions, and as would naturally be expected, the results were very erratic and are not conclusive. Prof. Wm. H. Burr concludes that the same values may safely be used for the modulus of elasticity in tension as in compression.

The values of E are only given for loads between 100 and 600, since these limits include the practical range of safe working stresses per square inch. For purposes of computing the ultimate strength, which would be for loads from 600 to 4,000 lbs., E would have considerably lower values. For loads between 1,000 and 2,000 lbs. the values would be from one-half to two-thirds of those given for loads between 100 and 600 lbs. For loads over 2,000 lbs. satisfactory data are not known to the writer. Table V gives values of the modulus of elasticity for stresses up to 2,000 lbs. per square inch as determined at the Watertown Arsenal in the series of tests made for Mr. Geo. A. Kimball, Chief Engineer of the Boston Elevated Railroad, in 1899. These determinations show that the modulus of elasticity is very much less at stresses between 1,000 and 2,000 lbs. per square inch than between 100 and 600 and 1,000 lbs. per square inch, but they are not sufficiently comprehensive to form the basis of any satisfactory rule or formula for the ratio of the modulus of elasticity to the stress per square inch.

TABLE V.—SHOWING REDUCTION IN VALUE OF E_c WITH INCREASING LOADS. VALUES GIVEN ARE THE MEAN OF THOSE FOR SEVERAL EXPERIMENTS WITH SEVERAL STANDARD BRANDS OF PORTLAND CEMENT.

Age.	Concrete 1 . 2 . 4.			Concrete 1 . 3 . 6.		
	100-600	100-1,000	1,000-2,000	100-600	100-1,000	1,000-2 000
7 days.....	2,592,000	2,053,000	1,351,000	1,869,000	1,529,000	
1 mo......	2,662,000	2,444,000	1,462,000	2,438,000	2,135,000	1,219,000
3 mos.....	3,670,000	3,170,000	2,157,000	2,976,000	2,656,000	1,805,000
6 mos.....	3,646,000	3,567,000	2.581.000	3,608,000	3,503,000	1,868,000

Professors Boeck and Melan found a value of E at about 750,000 in connection with the Austrian experiments, where a number of arches were tested to destruction. In calculations of ultimate strength by formulas, assumed values of E ranging from 1,500,000 to 750,000, according to the mixture, age, and the ultimate load per square inch. would seem to agree more nearly with the average of previous experiments than values of E corresponding to loads much less than the ultimate strength.

Two important points to be noted in connection with this subject are that the elastic limit of concrete, so far as it has been determined, is very close to the ultimate strength, and that its stress-strain diagram is a curve, instead of being practically a straight line as it is with steel inside of the elastic limit . The nature of this curve cannot be determined from the limited number of determinations that have been published.

Working Loads.—In Table VI are given what are considered safe working loads, in pounds per square inch, and properties for concretes in which the mortar or matrix is 1 of cement to 2 of sand and 1 of cement to 3 of sand, and in which all the voids in the aggregate are filled. According to present practice, these mixtures will about cover the range for reinforced concrete.

Properties of Steel.—The following properties of steel for use in computing reinforced concrete sections, with the values assigned to them, will be used herein. These values are believed to be safe, but may be varied as conditions require, according to the judgment of the designer:

Ultimate strength, 58,000 to 66,000 lbs. per square inch.

Elastic limit, 55 per cent. of the ultimate strength.

Modulus of elasticity, 29,000,000.

Working stress, factor of 4, 15,000 lbs. per square inch.

Working stress, factor of 5, 12,000 lbs. per square inch.

Rate of expansion per degree Fahrenheit, 0.00000648 to 0.00000686.

Relations Between Concrete and Steel.—The character of the relations that exist between the concrete and steel elements of reinforced concrete combinations depends first on the design of the section. If the

two elements act independently in resisting the stresses, so that either the one or the other might carry all the load, it may be called a *composite design.*

If some of the forces are resisted entirely by the steel and other forces resisted entirely by the concrete, so that if the element resisting one force failed the entire section would fail, it may be called a *combination design.*

If the disposition of the steel and the concrete in the section is such that the two elements act as a single unit, all stresses being divided between the concrete and the steel, where the latter occurs, and that the entire omission of the steel would only result in reducing the strength of the section, it may be called a true *monolithic design.*

While many composite designs have been loosely classed with "concrete-steel," they really have little in common with the combination and monolithic designs. Since the concrete and the steel are independent of each other, and either one may carry all the load, it is clear that each element should be calculated independently and like an all-concrete or an all-steel section, as the case may be. This is not to

TABLE VI.—SHOWING SAFE WORKING STRESSES FOR CONCRETE.

Mixture.	1 to 2 Matrix.				1 to 3 Matrix.			
Age.	1 Month		6 Months.		1 Month.		6 Months.	
Safety factor	6	5	6	5	5	5	5	5
Compression, lbs.*	400	500	600	700	340	400	500	600
Tension, lbs.	40	50	60	70	35	40	50	60
$f=\frac{M}{S}$	64	80	96	112	56	64	80	97
Shearing	50	62	75	87	44	50	62	75
E	2,600,000		3,600,000		2,300,000		3,360,000	

Rate of expansion per degree Fahrenheit	(Clark)	.00000795
	(Rae and Dougherty)	.00000655 for 1 : 3 : 5 concrete
	(Rae and Dougherty)	.00000561 for 1 : 2 mortar
Adhesion to iron or steel metalic surface, ultimate	(Bauschinger)	570 to 640 pounds per square inch
	(Hatt)	636 to 756 pounds per square inch
Safe working adhesion		60 to 100 pounds per square inch

* These values for compression are intended for use with the straight-line formulas only. For the formulas of the parbolic type they should be reduced, as the latter give larger moments of resistance (M_0) than the straight-line formulas for the same value of compression in the extreme fibers (f_c').

Note.—Prof. Hatt also found that the friction of smooth round rods embedded in concrete after they started to slip was from 50 per cent. to 70 per cent. of the adhesion.

For concrete not reinforced with steel, use two-thirds the values given in the tables for tension and $f=M \div S$.

imply that the concrete may not stiffen the steel and prevent it from buckling, but as they do not act together as a combination or unit, and as the steel does not reinforce the concrete, except in the manner that any additional and independent section may reinforce another, designs of this type should scarcely be classed with concrete steel or reinforced concrete.

Combination designs include concrete-steel beams after the concrete on the tension side has been strained beyond the point of rupture, which will occur in a well-designed beam long before the ultimate strength of the beam is reached. Concrete beams reinforced with steel, under loads that produce maximum tensile stresses in the concrete less than the ultimate strength, act as a single unit and may be classed as monolithic.

The most important characteristics or properties required to determine the distribution of stresses between the concrete and steel are the relations existing between the following:

A_c=area of the section of the concrete.

A_s=area of the section of the steel.

E_c=the modulus of elasticity of the concrete.

E_s=the modulus of elasticity of the steel.

Under direct compression or tension the stresses will be distributed between the two elements in the proportion of $F_c:F_s::A_cE_c:A_sE_s$, where

F_c=the total stress in the concrete

and

F_s=the total stress in the steel.

From this is derived the equation

$$F_s=F_c\frac{A_sE_s}{A_cE_c}, \quad \ldots \ldots \quad (1)$$

and if $f_c=\frac{F_c}{A_c}=$ the stress per square inch in the concrete and $f_s=\frac{F_s}{A_s}=$ the stress per square inch in the steel, we have

$$f_s=f_c\frac{E_s}{E_c}, \quad \ldots \ldots \quad (2)$$

which is to say that the stress per square inch in the two elements is directly proportional to their respective moduli of elasticity. This is derived directly from the definition of the modulus of elasticity which is the ratio of the stress per unit of section to the deformation. When the modulus of elasticity for steel is stated to be 29,000,000, it means that one pound per square inch tension or compression will stretch or compress the section an amount equal to its length divided by 29,000,000, and if E_c, for the concrete, is 1,933,333, one pound per square inch will stretch or compress it an amount equal to its length divided by 1,933,333. If $\frac{E_s}{E_c}=\frac{29,000,000}{1,933,333}=15$, and if the same intensity of stress per square inch exists in both the concrete and the

steel, the concrete will be deformed fifteen times as much per unit of length as the steel, or in the ratio $\frac{E_s}{E_c}$. If, however, the stress per square inch in the steel is fifteen times that in the concrete, or in the ratio of E_s: E_c, then the deformation will be the same per unit of length in both. Unless this latter condition maintains in every part of a concrete and steel structure of any description the surfaces of the two elements in contact will slide over each other or the concrete near the steel element will be strained beyond its elastic limit or its ultimate resistance.

While it is the invariable practice to meet this condition in the design of arches, columns, etc., concrete-steel beams are quite generally designed on the theory that the steel does all the work on the tensile side of the neutral axis. There is no doubt whatever that the concrete on the tensile side of a well-designed reinforced concrete beam will fail long before the ultimate strength of the beam is reached, since most all of the tests to destruction have demonstrated it to be so. This theory will be treated at some length in the chapter on beams.

Coefficient of Expansion.—The thermal changes in reinforced concrete have ceased to be a matter for discussion from a practical viewpoint, and have been relegated to the laboratories for the determination of the last decimal in the rates of expansion. Some of the most recent and reliable determinations made by Rae and Dougherty at Columbia University and by Prof. W. D. Pence at Purdue University gave the rate of expansion for Portland-cement concrete with various proportions of sand and stone or gravel, such as are generally used in practice, at 0.00000545 to 0.00000655 per degree Fahrenheit. The later value by Rae and Dougherty is perhaps the more reliable, as the experiments were conducted with great care. Clark gives the rate at 0.00000795, which averaged with the mean of Prof. Pence's determination, 0.00000545, gives 0.00000670. This is less than 2½ per cent. greater than the value given by Rae and Dougherty.

The rate of expansion per degree Fahrenheit for wrought-iron and steel is given by Kent at 0.00000648 to 0.00000686, and by U. S. Reports on Iron and Steel at 0.00000617 to 0.00000676. The mean of these is about 0.00000657. From this it appears that the difference in the rate for concrete and for steel is only a fraction of 1 per cent.

Aside from this the large number of reinforced concrete structures that have been exposed to the weather in severe climate for years without any indication of injurious effect from thermal changes is a sufficient proof that if there is any difference in the rate for the two materials, it is not enough to be of consequence.

Adhesion Between Concrete and Steel.—Next in importance to the ratio between the stress per square inch and the moduli of elasticity is the adhension between the concrete and the steel. Table VI gives the ultimate and safe working values of this property in pounds per square inch. In the design of any combination or monolithic member of reinforced concrete the bond between the two elements is of vital impor-

tance. In the majority of cases met in practice, the relation between the elements is such that the entire stress in the steel must be transmitted to it by this bond of adhesion. When the shear per foot run between the steel and concrete exceeds the safe working adhesion, resort must be had to a mechanical bond. Various devices have been used to obtain an effective bond, such as corrugating or twisting square or flat rods or bars, driving rivits in flat bars, the projecting heads of which serve the purpose, and deforming round rods so that they are made up of alternate round and flat sections but with the same sectional area at every point.

Some engineers have objected to the use of square or flat sections on the ground that the sharp re-entering angles formed in the concrete weaken the latter and induce cracks to start from the angle when subjected to loads or shocks. In cast-iron, a material that has several properties similar to those of concrete, re-entering angles greatly weaken the sections, and therefore castings are generally boldly filleted at such angles. The writer does not know of any tests that throw light on this question, but notwithstanding the fact that considerable concrete has been reinforced with square and flat steel, it would seem to be safer and conservative practice to avoid all sharp re-entering angles in concrete. By far the larger part of all the reinforced concrete in Europe has been made with round rods or wires In some cases steel angles, I-beams, or T's have been used, but squares and flats, if used at all, do not seem to have met with general favor. Tests more recently made in America indicate a considerable gain in ultimate strength of reinforced-concrete beams when rods are used that give a mechanical bond, as compared with beams made with plain rods.

As this second edition is just going to press, reports on the effect of the California earthquake on buildings of different types of construction are just beginning to come in. These are as yet too meagre to form the basis of any conclusion. It is worthy of note, however, that the buildings with steel frames have stood the test very well, and that, of the Leland Stanford University Buildings, at Palo Alto, the damage was confined almost entirely to those with brick or stone masonry walls, while some buildings with monolithic concrete walls, not reinforced, escaped with little or no injury. Some of these buildings had concrete floors, reinforced with twisted rods, which are reported to have stood the test satisfactorily. It would seem to be prudent, in designing reinforced concrete buildings, in localities subject to earthquake, to plan the reinforcing steel members so that they would be everywhere tied together and of such strength that they would be in stability without assistance from the concrete.

The late Mr. Geo. S. Morrison, in an address approving the principle of reinforced concrete, referred to such construction as "concrete structures with metal structures inside." If the writer interprets this correctly, Mr. Morrison referred to structures in which the metal elements alone would form a complete and stable structure,

though not necessarily one of sufficient strength to carry the required loads. This conception of a reinforced concrete structure seems to the writer to be the correct one, but, of course, it is not the cheapest that can be built. Many errors are made in attempting to keep down first cost, and such errors enter into a larger proportion of the structures built during the early stages of the development of any new method or system of construction than they do afterwards. As an example of this, all of our early metal bridges in the United States were built too light, even for the loads then in vogue, and we have come to adopt much heavier details than would previously have been used for the same duty. The writer believes that this applies with a special force to reinforced-concrete construction and that the development of design will tend toward the idea of making the embedded metal parts at least capable of supporting themselves in their position in the structure without assistance or connections from the concrete in which they are to be embedded. Of course, this does not refer to all kinds of structures, but more especially to reinforced-concrete buildings. The Melan system of arch construction is a good illustration of this idea, as its reinforcement consists of a perfect metal arch, which is, in stability, without any assistance from the concrete and is sometimes made sufficiently strong to carry the entire load.

COSTS.

In considering a material to be used in building, one of the first things that an owner asks is, "What is the cost," and usually this means the first cost, forgetting to consider the most important factor, the cost of maintenance and repairs, and the insurance, which runs on year after year.

The first is practically the whole cost in using Reinforced Concrete, as compared to other building materials, and this varies according to the character of the construction and the purchase price of materials.

While the article in the opening pages by Walter Loring Webb C. E. touches on the subject of cost, the following paragraphs selected from Page 24 of Taylor & Thompson's volume, "Concrete Plain and Reinforced," contain some interesting data:

APPROXIMATE COST OF CONCRETE.

The cost of concrete depends more upon the character of the construction and the conditions which govern it than upon the first cost of the materials. In a very general way, we may say that when laid in large masses or in a very heavy wall, so that the construction of the forms is relatively a small item, the cost per cubic yard in place is likely to range from $4 to $7. The lower figure represents contract work under favorable conditions with low prices for materials, and the higher figure small jobs and inexperienced men. Similarly, we may say that for sewers and arches, where centering is required, the price may range from $7 to $14 per cubic yard. Thin building walls, under eight inches thick may cost from $10 to $20 per cubic yard, according to the character of construction and the finish which is given to the surface.

These ranges in price seem enormous for a material which is ordinarily supposed to be handled by unskilled labor, but it must be borne in mind that skilled workmen are required for constructing forms and centers, and often the labor upon these may be several times that of mixing and placing the concrete. As a rule, unless the job is a very small one or under the personal supervision of a competent engineer, it is cheaper and more satisfactory to employ an experienced contractor than day labor. Green men under an inexperienced foreman may not be counted upon to mix and lay over one-half the amount of concrete that will be handled by a skilled gang under expert superintendence.

A close estimate of cost may be reached, in cases where the conditions are known in advance, by taking up in detail and then combining the various units of the material and labor as outlined below.

Cost of Cement. As the price of Portland cement varies largely with the demand, it is necessary to obtain quotations from dealers for every purchase. It is such heavy stuff that the freight usually enters largely into the cost, and quotations should therefore be made f.o.b. the nearest point of delivery to the work. The cost of hauling by

wagon may be readily estimated by assuming that a barrel of cement weighs 400 pounds (gross), and that a pair of horses will haul over an average country road a load of, say 5,000 pounds, traveling in all a distance of 20 to 25 miles in a day, that is, 10 to 12½ miles with load. This assumes, of course, that the teams are good and properly handled.

Having found the cost of the cement per barrel, delivered, the approximate cost per cubic yard is at once obtained from the table on page 17. If, for example, the cost is $2 per barrel and proportions 1:2½:5 are selected, the cost of the cement per cubic yard of concrete will be 1.29×$2.00=$2.58.

Cost of Sand. The cost of sand depends chiefly upon the distance hauled. With labor at 15 cents per hour, the cost of loading (including the cost of the cart waiting at pit) may be estimated, if handled in large quantities, at 18 cents per cubic yard, or on a small job at 27 cents per cubic yard. For hauling add one cent for each 100 feet of distance from the pit. The additional cost of screening, if required, will vary with the coarseness of the material, but 15 cents per cubic yard may be called an average price for this, unless the sand is obtained by screening the gravel, when no allowance need be made. After finding the cost of one cubic yard of sand, the cost of the sand per cubic yard of concrete is readily figured from the table referred to. If, for example, the cost of sand screened, loaded and hauled 1,000 feet is 52 cents per cubic yard, the cost per cubic yard of concrete for proportions 1:2½:5 will be 0.45×$0.52=$0.23½.

Cost of Gravel or Broken Stone. If broken stone is used upon a small job for the coarse aggregate, it is usually purchased by the ton or cubic yard. A 2000-lb. ton of broken stone may be considered as averaging approximately 0.9 cubic yards, although differences in specific gravity cause considerable variation. A two-horse load is generally considered 1½ to 2 yards, the latter quantity requiring very high sideboards. The cost of screening gravel, if this is necessary, while a very variable item, may be estimated at 35 cents per cubic yard. The cost of loading gravel into double carts, with labor at 15 cents per hour, may be estimated on a small job at 38 cents per cubic yard. If handled in large quantities 25 cents is an average cost. The cost of loading, includes loosening and also the cost of the cart waiting at the pit. Hauling costs about one cent per cubic yard additional for each 100 feet of distance hauled under load. If, to illustrate, the cost of gravel picked, screened, loaded and hauled 1000 feet is 83 cents per cubic yard, the cost of the gravel per cubic yard of concrete for proportions 1:2½:5 will be 0.91×$0.83=$0.75½.

For distances up to 300 feet both sand and gravel can be hauled more economically by wheelbarrows than by teams. The cost of loading wheelbarrows is about half the cost of loading carts, while the cost of hauling with barrows per 100 feet is about four times greater.

Cost of Labor. With an experienced gang working at the rate of 15 cents per hour, the cost of mixing and laying concrete, if shoveled directly to place from the mixing platform, will average about 80 cents

per cubic yard, in addition to the work on forms. If, as is usually the case, the concrete is wheeled in barrows, 9 cents per cubic yard must be added to the above price for the first 25 feet that the barrows are wheeled under load, and 1¼ cents for each additional 25 feet wheeled. With other rates of wages, the cost may be considered as proportional. With a green gang, the cost will be nearly double the above figures, but as the men become worked in and organization perfected, the cost should approximate more nearly the prices given.

The labor on forms is not included in the above. This is an extremely variable item. The cost of building rough plank forms (not including cost of lumber) on both sides of a 5-foot wall may be as low as 14 cents per cubic yard of concrete, with other thicknesses of wall in inverse proportion. On elaborate work the price, which is really dependent upon the face area, may reach several dollars per cubic yard of concrete.

THE STRENGTH OF CONCRETE.

The strength of concrete varies (1) with the quality of the materials; (2) with the quantity of cement contained in a cubic yard of the concrete; and (3) with the density of the mixture.

We may say that the strongest and most economical mixture, consists of an aggregate comprising a large variety of sizes of particles, so graded that they fit into each other with the smallest possible volume of spaces or voids, and enough cement to slightly more than fill all of these spaces or voids between the solids of the aggregate. It is obvious that with the same aggregate the strongest cement will make the strongest concrete.

On important construction the various materials to be used should be carefully tested, and specimens of the mixture selected made up in advance and subjected to test. As a guide to the loads which concrete will stand in compression,—that is, under vertical loading where the height of the column or mass is not over, say, 12 times the least horizontal dimension,—we may give the following approximate figures as safe strengths, after the concrete has set at least one month, for the proportions which have previously been selected in this article as typical mixtures.

The figures, compared with the results of recent experiments on 12-inch cubes, allow a factor of safety of six at the age of one month, or eight at the age of six months, and are based on conservative practice. The relative strengths of the different mixtures are calculated from original investigations of the authors discussed in Chapter XIII.

Safe Strength of Portland Cement Concrete in Direct Compression.

Proportions	Pounds per square inch.	Tons per square foot.
1:2:4	410	29
1:2½:5	360	25
1:3:6	325	23
1:4:8	260	18

With a large mass foundation, take values one-eighth greater.
With a vibrating or pounding load, take one-half these values.

The tensile strength of concrete is very much less than the compressive strength. Experiments made by the authors, with mixtures of average proportions, give the ultimate fiber stress in beams as about one-eighth the breaking strength in compression.

STEEL FOR REINFORCING.

While there may or may not be advantages in using a high carbon, high tensile strength steel in reinforcing-concrete, the opinion in general seems to be in favor of a medium or mild steel. A tensile strength of 64,000 lbs. per square inch is about the minimum breaking point of ordinary mild commercial steel, while high carbon, high tensile strength steel will often run as high as 150,000 lbs. per square inch, and if used, less steel is required. But owing to the brittle nature of high carbon steel, as well as the difficulty in securing a uniform quality, it appears more dangerous to use.

The Coefficient or Modulus of Elasticity being one of the governing factors in reinforcing concrete, and this remaining the same in either a high or low carbon steel, it is usually more desirable to use a mild or commercial steel for reinforcing purposes.

We reprint below by permission on this subject, "Quality of Reinforcing Steel," from Page 291 "Concrete Plain & Reinforced," by Taylor & Thompson:

Quality of Reinforcing Steel.—It is generally recognized that in beam design the yield point of the steel shall be considered as the point of failure of this material in a reinforced beam. Tests show that when the metal reaches its yield point, the beam sags, and this deflection, due to the stretch of the steel, and in some cases to the slipping of the steel because of its reduced cross-section, is likely to produce crushing in the concrete.

The yield point of ordinary mild steel purchased in the open market, as determined by the drop of the beam in testing (the true elastic limit is several thousand pounds lower), cannot safely be fixed at a higher value than 30,000 pounds per square inch, although frequently, and in fact in the majority of cases, a value of at least 36,000 pounds and in many cases 40,000 pounds, will be found.

High steel, that is, steel containing a high percentage of carbon, has a much higher yield point than mild steel. If of first-class quality,* a minimum yield point may be placed at 50,000 or 55,000 pounds per square inch and much of it will reach 60,000 pounds. The ultimate strength should be not less than 105,000 pounds per square inch. Thus, if it can be safely employed in reinforced concrete, it is adapted to carry much higher stress than mild steel, and, conversely, a smaller percentage of it is required for the same moment of resistance. Many engineers do not approve of the use of high steel because of its brittleness, when of poor quality, and the danger of sudden accident, and because of the fact that it is prohibited in ordinary structural steel work.

Mild steel, that is, ordinary market steel, is manufactured and sold under such standard conditions that it may be safely used without test. High steel, on the other hand, must be very thoroughly tested. When tested, however, as per our specifications, page 38, it is entirely

*See Specifications for First-class Steel, p. 38.

safe and to be preferred to mild steel. The objection to it for reinforced concrete is based largely upon the use of a poor quality of material. Another objection which has been raised is that before the elastic limit is reached, the stretch in the high steel may produce an excessive cracking in the concrete in the lower portion of the beam, and thus expose the steel to corrosion. The mere fact that cracks are visible does not prove that they are dangerous, because the steel is always designed to take the whole of the tension. This point remains to be definitely settled, but Mr. Considere's and Professors Talbot's and Turneaure's tests indicate that there is no dangerous cracking even with high steel until the yield point of the steel is reached. This fact can be positively determined by cutting sections from reinforced concrete beams which have been strained nearly to the elastic limit, and testing them for corrosion by the methods employed by Prof. Charles L. Norton. (See p. 427.) A yield point in steel of 30,000 pounds per square inch corresponds to a stretch of 0.0010 of its length and a yield point of 50,000 to a stretch of 0.00167. (See p. 290.)

A steel with a high modulus of elasticity would be particularly serviceable for reinforced concrete, because the higher the modulus of elasticity of a material, the less is the deformation under any given loading. Unfortunately, however, a high carbon steel has substantially the same modulus of elasticity (30,000,000 lb. per sq. in.) as ordinary merchant steel.

The brittleness feared in high steel is less dangerous in reinforced concrete than in many classes of structural steel work because the concrete protects it from shock, and also because smaller sections of steel are used in concrete beams than in steel beams, and the large and irregular shapes of the latter render them much more sensitive to irregular cooling during the process of their manufacture.

It may be stated, then, if the stretching of high steel when pulled to its allowable working stress is proved not to form dangerous cracks in the concrete, that high carbon steel, say, 0.56% to 0.60% carbon, of the quality used in the United States for making locomotive tires, is always better than mild steel for reinforced concrete provided the steel is well melted and rolled, and is comparatively free from impurities, such as phosphorus. However, a high carbon steel, unless limited by chemical analysis, and made under careful inspection, is in danger of being more brittle than low carbon steel. Its use, therefore, should be limited strictly to work important enough to warrant the ordering of a special steel and the taking of sufficient trouble on the part of the purchaser to insure strict adherence to the specification. Under such circumstances, the use of high steel is attended with much economy. In other words, since manufacturers cannot always be depended upon to exactly follow specifications of this nature, it is necessary that an inspector be sent to the works, or else that the steel be purchased from a reliable dealer who has had it thus carefully tested.

The specifications for first-class steel on page 38 are sufficiently explicit so that steel which comes up to them can be safely used. A steel which can be employed with safety for all the locomotive and car wheels of the country certainly cannot be discarded as unsafe for concrete, provided similar precautions are taken in its purchase.

From Page 68, "Reinforced Concrete," by Buel & Hill:

Grade of Steel.—The quality of steel used in reinforcing concrete should be as carefully specified as for an all-steel structure doing the same duty. Some engineers advocate the use of high steel, on account of its high elastic limit, which recent tests show gives a higher ultimate strength to the beam. The breaking load for beams having the proper amount of reinforcement appears to be at about the elastic limit of the steel. In most cases, and certainly in structure subject to shock or impact, the writer considers it better and more conservative practice to use medium or mild structural steel, except for reinforcement for thermal and shrinkage stresses only, where high steel appears to be preferable.

PROTECTION OF STEEL OR IRON FROM CORROSION.

Most tests which have been conducted of steel imbedded in concrete have resulted in positive proofs of the protection offered by Portland cement concrete, not only from corrosion or rust, but from the most severe fire that is liable to occur. Of course, the steel must be imbedded of sufficient depth in the concrete to obtain these results,—from one to two inches being usually accepted as a safe distance from the surface. While these results are not as readily obtained with a cinder concrete, yet by being thoroughly wet and well mixed, they should be.

Many engineers condemn cinder concrete owing to its extremely porous nature, thereby allowing the moisture and air to penetrate to the steel, which in a comparatively short time will rust it out entirely. In many instances the corrosion of steel in cinder concrete has been attributed to the sulphur contained in the cinders; this, however, is not now accepted as the cause, but is due to the fact that it has not been mixed thoroughly and sufficiently wet.

Cinders often contain Oxide of Iron, and when this is the case, and the mixture is not sufficiently wet to give the steel a thorough coating with cement, it quickly corrodes any steel with which it comes in contact.

The following pages: "Preservation of Iron in Concrete," reprinted from Chapter XII, "Reinforced Concrete," by Buel & Hill, contains some interesting tests on this subject:

Preservation of Iron in Concrete.—It has generally been assumed that iron or steel embedded in concrete does not corrode, and many instances are cited of embedded steel being removed from concrete quite as clear and bright after a long period of exposure to the elements as it was when first embedded. It should be noted, however, that an occasional instance is cited to show that under certain circumstances metal embedded in concrete will corrode. As the durability of concrete-steel requires that the steel shall be permanently protected from corrosion, this question is an important one and it has received consideration from a number of experts. The commonly accepted theory accounting for the protection from rust of iron embedded in concrete has been recently stated by Prof. Spencer B. Newberry as follows:

The rusting of iron consists in oxidation of the metal to the condition of hydrated oxide. It does not take place at ordinary temperatures in dry air or in moist air free from carbonic oxide. The combined action of moisture and carbonic acid is necessary. Ferrous carbonate is first formed; this is at once oxidized to ferric oxide and the liberated carbon dioxide acts on a fresh portion of metal. Once started the corrosion proceeds rapidly, perhaps on account of galvanic action between the oxide and the metal. Water holding carbonic acid in solution soon, if free from oxygen, acts as an acid and rapidly attacks iron. In lime-water or soda solution the metal remains bright. The action of cement in preventing rust is now apparent. Portland cement contains about 63 per cent. lime. By the action of water it is

converted into a crystalline mass of hydrated calcium silicate and calcium hydrate. In hardening it rapidly absorbs carbonic acid and becomes coated on the surface with a film of carbonate, cement mortar thus acting as an efficient protector of iron and captures and imprisons every carbonic-acid molecule that threatens to attack the metal. The action is, therefore, not due to the exclusion of the air, and even though the concrete be porous, and not in contact with the metal at all points, it will still filter out and neutralize the acid and prevent its corrosive effect.

The use of cement washes and plasters for the specific purpose of protecting iron and steel from rust is quite common and has extended over a long period of time. Cement paint is largely used by the railway companies of France to protect their metal bridges from corrosion. Two coats of liquid cement and sand are applied with leather brushes. After investigation and careful tests the engineers of the Boston Subway adopted Portland-cement paint for the protection of the steel beams of that structure. Iron spirit-tanks for European distilleries are universally painted on the inside with Portland-cement paint to prevent corrosion. In the United States it is a frequent practice to coat the inside of steel salt-pans, sulphate digesters, etc., with cement plaster to prevent corrosion. Regarding the damage from corrosion by the sulphur in the cinders of cinder concrete Prof. Newberry expresses himself as follows:

The fear has sometimes been expressed that cinder concrete would prove injurious to iron on account of the sulphur contained in the cinders. The amount of this sulphur is, however, extremely small. Not finding any definite figures in this point, I determined the sulphur contained in an average sample of cinders from Pittsburg coal. The coal in its run state contains a rather high percentage of sulphur, about 1.5 per cent. The cinders proved to contain only 0.61 per cent. sulphur. This amount is quite insignificant, and even if all oxidized to sulphuric acid it would at once be taken up and neutralized in concrete by the cement present, and would by no possibility attack the iron.

In connection with this statement it may be noted that in the demolition in 1903 of a tall steel-frame building in New York City, which was built in 1898 and had practically all of its framework except the columns embedded in cinder concrete, the steel removed showed practically no rust which could be considered as having developed after the metal was embedded.

Tests of a reliable character, made to determine the efficiency of concrete in protecting embedded metal from corrosion, are comparatively few. The most important ones which have been published are those of Mr. Breuillie of France and those of Prof. Charles L. Norton of Boston, Mass. Mr. Breuillie's tests were extended in character and the conclusions drawn from them by the experimenter were: (1) That the cement attacked the iron; (2) that water dissolved the composition which formed at the contact of the two materials; (3) that the adhesion of the steel to the cement disappeared when water passed through the concrete for a certain time; (4) that the weight of the iron salts which adhered to the steel and the normal adhesion between

the steel and the concrete increased with time; (5) in all cases the action of the cement on the iron prevented rust and removed the rust from metal which had ben allowed to corrode before being embedded.

The tests conducted by Prof. Charles L. Norton of the Massachusetts Institute of Technology, Boston, Mass., were of a somewhat different character from those of Mr. Breuillie. Briquettes or blocks were made of neat cement; of 1 part cement and 3 parts sand; of 1 part cement and 5 parts broken stone, and of 1 part cement and 7 parts cinders. Portland cement was used, and was tested chemically and physically and found good. The cinders when washed down with a hose-stream and dried tested alkaline, and analysis revealed very small amounts of sulphur. In each block there was embedded a ¼-in. rod, a piece of soft sheet steel $6 \times 1 \times 232$ in., and a 6×1-in. strip of expanded metal. These blocks were exposed as follows: one-quarter of them in sealed chests containing an atmosphere of steam, air, and carbon dioxide; one-quarter in a similar chest with an atmosphere of air and carbon dioxide; one-quarter in a chest with an atmosphere and steam, and one-quarter on a table in the open air of the testing-room. At the end of three weeks the blocks were carefully cut open, and the steel examined and compared with specimens which had lain unprotected in the corresponding chests and in the open air.

The results of the examinations were as follows: The unprotected specimens consisted of rather more rust than steel. The specimens embedded in neat cement were perfectly protected. Of the remaining specimens hardly one had escaped serious corrosion. The location of the rust-spot was invariably coincident with either a rod in the concrete or a badly rusted cinder. In the more porous mixtures the steel was spotted with alternate bright and badly rusted areas, each clearly defined. In both the solid and the porous cinder concrete many rust-spots were found, except where the concrete had been mixed very wet, in which case the watery cement had coated nearly the whole of the steel, like a paint, and protected it. The following are Prof. Norton's conclusions from his tests:

(1) Neat Portland cement, even in thin layers, is an effective preventative of rusting.

(2) Concrete, to be effective in preventing rusting, must be dense and without voids and cracks. It should be mixed quite wet when applied to the metal.

(3) The corrosion found in cinder concrete is mainly due to the iron oxide, or rust, in the cinders and not to the sulphur.

(4) Cinder concrete, if free from voids and well rammed when wet, is about as effective as stone concrete in protecting steel.

(5) It is of the utmost importance that the steel be clean when bedded in concrete. Scraping, pickling, a sand-blast, and lime should be used, if necessary, to have the metal clean when built into a wall.

At first sight the conflicting testimony which has been quoted appears to have but little solid ground upon which the practicing engineer can base a decision as to the probable damage from rust of

iron or steel embedded in concrete. A brief analysis will show, however, that this is not actually the case. In the first place there are many instances where steel embedded in concrete has shown no signs of rust upon removal. None of the evidence presented disputes this fact. Secondly, steel removed from concrete which contained cracks or voids has in many instances shown rust, always at the points where the cracks and voids were located. None of the evidence presented disputes this fact. Thirdly, the theory that the concrete covering filters out and renders innocuous the corrosive elements so completely as to protect the steel even where it is not in contact with the concrete is disputed by the results of Prof. Norton's tests. Fourthly, Prof. Norton's tests show that where the concrete is so closely in contact with the steel as to completely cover it with cement there is no corrosion. This fact is not disputed by any of the other evidence. Fifthly, Prof. Norton's tests show that wet concrete mixtures more certainly insure the close contact of the steel and concrete at all points than do dry mixtures. This fact is not disputed by any of the other evidence. Sixthly, Prof. Norton's contention that the steel should be perfectly cleaned before it is bedded in concrete is controverted by the tests of Mr. Breuille, which show that bedding in concrete will remove the rust from previously corroded steel. Seventhly, all the evidence presented indicates that the sulphur content of the cinders is not a serious element of danger in cinder concrete and that, other conditions being the same, cinder concrete and stone concrete are about equally efficient in preventing the rusting of embedded steel. The useful conclusion which the practicing engineer can draw from all this is that, so far as danger from subsequent rusting is concerned, he can confidently embed steel or iron reinforcement in either cinder or stone concrete if he secures a close contact between the concrete and steel at all points, and if no cracks develop in the concrete to expose the metal to attack.

FIRE PROTECTION.

The value of concrete as a fireproofing is apparently unquestionable, not alone from laboratory experiments, etc., but from fires which have actually occurred in buildings where this material has been employed.

The following from Page 431 of Taylor & Thompson's volume, "Concrete Plain & Reinforced, contains some very interesting results of both tests and actual fires:

Numerous experimental tests* have been made showing the value of concrete as a fire-resisting material, but the best proof of its ability to resist the heat of a severe fire—such as is liable to occur in an office or factory building— lies in the fact that concrete has actually withstood very severe fires more successfully than have terra-cotta and various other so-called fireproof materials.

The reinforced concrete factory of the Pacific Coast Borax Co. at Bayonne, N. J., passed through a severe fire in 1902. Still more recently, in 1904, occurred the conflagration at Baltimore in which many building materials utterly failed.

Such practical tests, further confirmed by numerous experiments with test buildings of reinforced concrete, have proved that while in a severe fire, where the temperature ranges from 1600° to 2000° Fahr., the surface of the concrete may be injured to a depth of from ½ to ¾ inch, the body of the concrete is unaffected, so that the only repairs required consist of a coating of plaster, and even this only in rare instances.

Tests upon small briquettes of cement placed in a furnace indicate that the strength of cement is destroyed by a heat reaching a dull, red color,† but as stated below, in an actual fire, the injured material protects the rest of the concrete so that the danger is theoretical rather than real.

Fire in Borax Factory. The fire in the 4-story reinforced concrete factory of the Pacific Coast Borax Company,‡ built entirely of concrete except the roof, utterly destroyed the contents of the building, the roof, and the interior framework, but the walls and floors remained intact except in one place where an 18-ton tank fell through the plank roof and cracked some of the floor beams, and in one place on the outside of the wall where the surface of the concrete was slightly affected. The fire was so hot that brass and iron castings were melted to junk. A small annex, built of steel posts and girders, was completely wrecked, and the metal bent and twisted into a tangled mass.

Baltimore Fire. The effect of the fire upon the concrete in various buildings located in the center of the burned districts of Baltimore

*See References, Chapter XXIX.
†Digest of Physical Tests, Vol. I, p. 217
‡See p. 463.

is best appreciated by an examination of the reports of experts upon the fire. Capt. John S. Sewell, in his report to the Chief of Engineers, U. S. A.,* in referring to the fire in one of the buildings built with reinforced concrete columns, beams, and arches, writes:

It was surrounded by non-fireproof buildings, and was subjected to an extremely severe test, probably involving as high temperature as any that existed anywhere. The concrete was made with broken granite as an aggregate. The arches of the roof and the ceiling of the upper story were cracked along the crown, but in my judgment very slight repairs would have restored any strength lost here. Cutting out a small section — say an inch wide — and caulking it full of good strong cement mortar would have sufficed. The exposed corners of columns and girders were cracked and spalled, showing a tendency to round off to a curve of about 3 in. radius. In the upper stories, where the heat was intense, the concrete was calcined to a depth of from ¼ to ¾ inch, but it showed no tendency to spall, except at exposed corners. On wide, flat surfaces, the calcined material was not more than ¼-inch thick, and showed no disposition to come off. In the lower stories, the concrete was absolutely unimpaired, though the contents of the building were all burned out. In my judgment, the entire concrete structure could have been repaired for not over 20% to 25% of its original cost. On March 10, I witnessed a loading test of this structure. One bay of the second floor, with a beam in the center, was loaded with nearly 300 pounds per sq. ft. superimposed, without a sign of distress, and with a deflection not exceeding ⅛-inch. The floor was designed for a total working load of 150 pounds per sq. ft. The sections next to the front and rear walls were cantilevers, and one of these was loaded with 150 pounds per sq. ft. superimposed, without any sign of distress, or undue deflection.

Captain Sewell concludes as a result of the examination of this and other buildings containing reinforced concrete construction:

As the material is calcined and damaged to some extent by heat, enough surplus material should be provided to permit of a loss of say ¾-inch all over exposed surfaces, if the structure is to be exposed to fire; moreover, all exposed corners should be rounded to a radius of about 3 inches. This latter precaution would add much to the resistance of all materials used in masonry—whether bricks, stone, concrete or terra-cotta—if they are to be exposed to fire.

Concrete Versus Terra-Cotta. Prof. Norton, in his report on the Baltimore fire to the Insurance Engineering Experiment Station,* says:

Where concrete floor arches and concrete-steel construction received the full force of the fire it appears to have stood well, distinctly better than the terra-cotta. The reasons I belive are these; First, because the concrete and steel expand at sensibly the same rate, and hence when heated do not subject one another to stress, but terra-cotta usually expands about twice as fast with increase in temperature as steel, and hence the partitions and floor arches soon become too large to be contained by the steel members which under ordinary temperature properly enclose them. Under this condition the partition must buckle and the segmental arches must lift and break the bonds, crushing at the same time the lower surface member of the tiles.

**Engineering News*, March 24, 1904, p. 276.
**Engineering News*, June 2, 1904, p. 529.

When brick or terra-cotta are heated no chemical action occurs, but when concrete is carried up to about 1 000° Fahr. its surface becomes decomposed, dehydration occurs, and water is driven off. This process takes a relatively great amount of heat. It would take about as much heat to drive the water out of this outer quarter-inch of the concrete partition as it would to raise that quarter-inch to 1 000° Fahr. Now a second action begins. After dehydration the concrete is much improved as a non-conductor, and yet through this layer of non-conducting material must pass all the heat to dehydrate and raise the temperature of the layers below, a process which cannot proceed with great speed.

Cinder Versus Stone Concrete. Prof. Norton compares the action of stone and cinder concrete in the Baltimore fire as follows:

Little difference in the action of the fire on stone concrete and cinder concrete could be noted, and as I have earlier pointed out, the burning of the bits of coal in poor cinder concrete is often balanced by the splitting of the stones in the stone concrete. I have never been able to see that in the long run either stood fire better or worse than the other. However, owing to its density the stone concrete takes longer to heat through.

Further experiments are required to determine the relative durability under extreme heat of concrete made with different kinds of broken stone. It seems probable, from the composition of the rock, that hard trap or gravel may be preferable to limestone, slate, or conglomerate as fire-resisting material.

Thickness of Concrete Required to Protect Metal from Fire. The conclusion reached by Prof Norton† from tests upon concrete arches is that two inches of good concrete gives perfect assurance of safety in case of fire, even if the steel to be protected is in the form of I-beams. Rods of small dimensions can be more effectively coated, and it appears evident from the various tests and from practical experience in severe fires that 1½ inches of concrete around steel rods is sufficient protection. The Pacific Borax Company's fire and other similar tests indicate that in slabs of reinforced concrete, ½ inch to ¾ inch affords ample protection. Secondary members, such as cross girders, or slabs of long span, should have a thickness of concrete outside of the steel varying from ¾ inch to 1½ inch. Although in slabs protected by only ½ inch of concrete, the latter may be softened by an extreme fire, and the metal exposed when it is struck by the stream from a hose, the metal in the majority of cases would still remain practically uninjured, and it is questionable economy to put an excess of material where there is so little probability of its being needed, and where a failure would merely produce local damage.

THEORY OF FIRE PROTECTION.

Mr. Spencer B. Newberry, in an address delivered before the Associated Expanded Metal Companies, Feb. 20, 1902,* gives the following explanation of the fire-proof qualities of Portland cement concrete:

†*Insurance Engineering*, Dec., 1901, p. 483.
**Cement*, May, 1902, p. 95.

The two principal sources from which cement concrete derives its capacity to resist fire and prevent its transference to steel are its *combined water and porosity*. Portland cement takes up in hardening a variable amount of water, depending on surrounding conditions. In a dense briquette of neat cement the combined water may reach 12%. A mixture of cement with three parts sand will take up water to the amount of about 18% of the cement contained. This water is chemically combined, and not given off at the boiling point. On heating, a part of the water goes off at about 500° Fahr., but the dehydration is not complete until 900° Fahr. is reached. This vaporization of water absorbs heat, and keeps the mass for a long time at comparatively low temperature. A steel beam or column embedded in concrete is thus cooled by the volatilization of water in the surrounding cement. The principle is the same as in the use of crystalized alum in the casings of fireproof safes; natural hydraulic cement is largely used in safes for the same purpose.

The porosity of concrete also offers great resistance to the passage of heat. Air is a poor conductor, and it is well known that an air space is a most efficient protection against conduction. Porous substances, such as asbestos, mineral wool, etc, etc., are always used as heat-insulating material. For the same reason cinder concrete, being highly porous, is a much better non-conductor than a dense concrete made of sand and gravel or stone, and has the added advantage of lightness. In a fire the outside of the concrete may reach a high temperature, but the heat only slowly and imperfectly penetrates the mass, and reaches the steel so gradually that it is carried off by the metal as fast as it is supplied.

MODULUS OR COEFFICIENT OF ELASTICITY.

Results of testing concrete for its Modulus of Elasticity for the same mixtures or proportions vary greatly. This is probably due to the exactness necessary in measuring the deformation of concrete. The Modulus of Elasticity of steel varies from 28,000,000 lbs to 31,000,000 lbs. per square inch; 29,000,000 or 30,000,000 being the values usually accepted for steel. Those for concrete, of course, vary with the proportion or the mixtures.

The following "Modulus of Elasticity," reprinted from Taylor & Thompson's, "Concrete Plain & Reinforced," Page 285 suggests the values for the Modulus of Elasticity of concrete:

Modulus of Elasticity. The modulus of elasticity of steel varies from 28,000,000 pounds per square inch to 31,000,000 pounds per square inch; 30,000,000 is customarily taken as an average value, and is the value which we have adopted.

The modulus of elasticity of concrete, a very important factor in reinforced concrete design, is considered in the preceding chapter, page 265. As there stated, it varies with the materials of which it is composed and with the proportions of these materials, also with the method of mixing and placing the concrete.

As tentative values for use in reinforced design, the authors suggest the following moduli for concrete mixed of the wet consistency usually employed in beams:

	Proportions	Modulus of Elasticity lbs. per sq. in.
Broken Stone or Gravel Concretes	1 : 1½ : 3	4 000 000
	1 : 2 : 4	3 000 000
	1 : 2½ : 5	2 500 000
	1 : 3 : 6	2 000 000
	1 : 5 : 8	1 500 000
Cinder Concrete................	1 : 2 : 5	850 000

It is probable that eventually these values will be found too low for dense, well-graded mixtures, which are gradually replacing those proportioned by rule of thumb methods. The authors have found a modulus of about 4 000 000 in 12-inch concrete cubes mixed 1: 2 1-3: 4 2-3, the crushing strength of which was about 5 000 pounds per square inch at the end of two months.

The higher the modulus of elasticity of the concrete, the lower should be the percentage of steel and the greater the depth of the beam for symmetrical design, that is, maintaining fixed relations of pull in steel to pressure in concrete.

From tests of Prof. W. Kendrick Hatt* the modulus of elasticity in tension appears to be of similar value to the compressive modulus. Earlier experimenters concluded that the modulus in tension is lower than in compression. A knowledge of the tensile modulus is, however,

*Journal Association Engineering Societies, June, 1904, p. 323.

of less consequence than the other because the tensile resistance of concrete is not usually considered.

It is probable that there is an increase in the modulus of elasticity* of concrete with age, but experiments by the author indicate that this is very slight.

Recent tests,* contrary to former ideas, indicate that under different loadings there may be slight change in the modulus of elasticity of a given concrete until near to its crushing strength. This fact is of importance in fixing the distribution of stresses in the beam.

Elongation or Stretch in Concrete. The question of "Elongation or Stretch in Concrete," is dealt within the succeeding paragraph, reprinted from Page 287 of Taylor & Thompson's volume.

According to tests of Prof. Turneaure, already mentioned, concrete under a pull, as in the lower portion of a beam, will usually stretch 0.0001 to 0.0002 of its length, that is, 0.01% to 0.02%, before showing minute cracks or "water-marks." Cracks become readily noticeable at a stretching varying, in different specimens, from 0.0003 to 0.0010 of their length. The concrete in a reinforced beam stretches similarly to the concrete in a plain beam except that in the latter the beam breaks when the limit of stretch is reached, while if reinforced, the pull is borne partly by the steel and partly by the concrete, and they both stretch together up to the point that cracks so minute at first as to be almost invisible occur in the concrete.

The action of the reinforced concrete is shown in the deflection curve in Fig. 89. The inclination of this curve changes at about the same load that is required to break a similar beam or plain concrete.

The diagram shows a typical result of Prof. Talbot's tests of the deformation of the concrete and the deformation of the steel, the deflection of the beam, and the various measured positions of the neutral axis during flexure. Among other conclusions, Prof. Talbot draws the following:

1. The composite structure acts as a true combination of steel and concrete in flexure during the first or preliminary stage, and this stage lasts until the steel is stressed to, say, 3 000 pounds per square inch, and the lower surface of the concrete is elongated about $\frac{1}{10000}$ of its length.

2. During the second or readjustment stage there is a marked change in distribution of stresses, the neutral axis rises, the concrete loses part of its tensional valve, and tensile stresses formerly taken by the concrete are tranferred to the steel. During this stage minute cracks probably exist, quite well distributed, and not easily detected.

3. In the third or straight-line stage the neutral axis remains nearly stationary in position and the concrete gradually loses more of its tensional value. Visible cracks appear and gradually grow larger, though no change in the character of the load-deformation diagram results. It would seem probable that at these cracks the stress in the steel is more than is indicated by the average deformation for the full gage length.

*See Discussion on Concrete, by Sanford E. Thompson, International Eng. Congress, St. Louis 1904.

Prof. Talbot states that at the load when the curve changes character,—which in the beam shown in the diagram is about 8 000 pounds total load, — there are probably invisible cracks in the lower portion of the beam. This change in direction of the curve, indicating a suddenly increased load upon the steel, is strong proof of the loss in tensional resistance of the concrete. Prof Turneaure, moreover, in his experiments, at loads somewhat beyond the point of change in direction, actually discovered these minute cracks. He tested his beams upside down, that is, the load was applied upward, and the minute cracks or water-marks were shown by hair lines on the wet surface of the concrete. Prof Turneaure* says:

It has been found that by testing the beams when somewhat moist, a crack is made visible when exceedingly small, it appearing first as a narrow, wet streak perhaps ⅛-inch wide and a little later as a dark hair-like crack. It was not necessary to search for the lines with a microscope as under these conditions they were readily found.

That the wet streak, called a "water-mark" hereafter, shows the presence of an actual crack was demonstrated last year by sawing out a strip of the concrete containing such a water-mark; the strip fell apart at the water-mark.

In the plain concrete no water-marks or cracks were observed before rupture. Comparing the observed and calculated elongations of the reinforced concrete with those for the plain concrete at rupture it will be seen that the initial cracking in the former occurs at an elongation practically the same as in the latter.

The significance of these minute cracks is an open question. It has been supposed that concrete reinforced by steel will elongate about ten times as much before rupture as will plain concrete. These experiments show very clearly that rupture begins at about the same elongation in both cases. In the plain concrete total failure ensues at once; in the reinforced concrete rupture occurs gradually, and many small cracks may develop so that the total elongation at final rupture will be greater than in the plain concrete. In other words, the steel develops the full extensibility of a non-homogeneous material that otherwise would have an extension corresponding to the weakest section.

*Proceedings American Society for Testing Materials, 1904

BONDING OLD AND NEW CONCRETE.

Too much attention cannot be paid by constructors or contractors to the bonding of old and new concrete. In most instances, sufficient care is not given to this in construction. The following from Page 376 of "Concrete Plain & Reinforced," Taylor & Thompson, should be carefully noted:

In a foundation or other structure where the strain is chiefly compressive, the surface of the concrete laid on the previous day should be cleaned and wet, but no other precaution. is necessary. Joints in walls or in other locations liable to tensile stress are coated with mortar, which should be richer in cement than the mortar in the concrete, proportions 1: 2 being commonly used.

Some engineers spread the cement dry upon the wetted surface of the old concrete, while others make it into a mortar; the latter method is necessary in many cases to seal the joints between the top of the old concrete and the bottom of the raised forms.

The adhesive strength of cement or concrete is much less than its cohesive strength, hence in building thin walls for a tank or other work which must be water-tight, the only sure method is to lay the structure as a monolith, that is, without joints. If the wall is to withstand water pressure and cannot be built as a monolith, both horizontal and vertical joints must be first thoroughly cleaned of all dirt and "laitance" or powdery scum, wet, and then covered with a very thin layer of either neat cement or 1: 1 mortar, according to the nature of the work. As an added precaution, one or more square or V-shaped sticks of timber, say 4 or 6 inches on an edge, may be imbedded in the surface, or placed vertically at the end of a section, of the last mass of concrete laid each day. In some instances large stones have been partially imbedded in the mass at night for doweling the new work next day.

In the New York Subway, work was commenced with no provision for bonding horizontal layers, but it was soon found that more or less seepage occurred, and in one case where a large arch was torn down the division line between two days' work was distinctly seen. Accordingly, at the end of each day's concreting a tongue-and-grooved joint was formed by a piece of timber 4 inches square partly imbedded in the top layer. This was removed before resuming work.

Roughening the surface after ramming or before placing the new layer will aid in bonding the old and new concrete.

EFFECT OF FREEZING.

The much discussed subject of the effect of freezing or frost upon Portland cement concrete seems to still be a question in the minds of many. This is possibly due, in some cases, to the confusion of Natural and Portland cements. Most natural cements are completely ruined by freezing, while Portland cements seem uninjured.

Numerous tests and investigations have been made in recent years, both in practical work and laboratories; the results being that the only permanent injury is to the surface, which may scale off in frozen before setting, and that the hardening and setting is retarded.

In practice the materials are often heated which causes the cement to set more quickly; or a limited amount of salt may be added to the water, with apparently no injury to the concrete.

The following reprinted from Chapter XIX, Taylor & Thompson's volume, "Concrete Plain & Reinforced," is most interesting:

Numerous experimental tests have been made, chiefly in the United States, where the effect of frost is a more serious question than in England, France, or Germany, to determine the effect of freezing temperatures upon hydraulic cements. Although the conclusions of different experimenters are not in perfect accord, it is the generally accepted belief, corroborated by tests under the most practical conditions and by the appearance of concrete and mortar in masonry construction, that the ultimate effect of freezing upon Portland cement concrete and mortar is to produce only surface injury.

In their practice and research the authors have never discovered a case, either in laboratory work or in practical construction, where Portland cement concrete or mortar laid with proper care has suffered more than surface disintegration from the action of frost. They do not wish to imply however, that it is always expedient to lay Portland cement masonry in freezing weather, for the expense of laying is increased, and it is much more difficult to satisfactorily mix and place the materials. Mortar for brick and stone masonry freezes in the tubs and in the joints, while in laying concrete the surface freezes unless measures are taken to prevent it, and any dirt or "laitance" which rises to the surface of wet mixtures is hard to remove. It is a well-known fact that a thin crust about $\frac{1}{16}$ inch thick is apt to scale off from granolithic or concrete pavements which have frozen, leaving a rough instead of a troweled wearing surface, and the effect upon concrete walls is often similar. It may be stated as a general rule that concrete work should, if possible, be avoided in freezing weather, although if circumstances warrant the added expense, with proper precaution and careful inspection mass concrete may be laid with Portland cement at almost any temperature.

Most Natural cements, on the contrary, are seriously injured by frost especially by alternate freezing and thawing, and while occasional cases are on record, especially in heavy stone masonry in

which the weighted joints have thawed slowly, where Natural cement mortar has been laid in freezing weather without serious results, numerous examples might be cited where even after several years the concrete or mortar was but slightly better than sand and gravel. Mr. Thompson has observed this result in Natural cement mortar laid during the comparatively warm winter of North Carolina on days when the temperature was considerably above freezing at the time of laying, and also in the cold climate of Maine where the mortar froze as it left the trowel and did not thaw until spring.

The settlement of the masonry when thawing is often a serious characteristic of Natural cements. Stone masonry walls laid in freezing weather in Natural cement mortar may settle as much as ½ inch in the height of a window jamb.

Experiments upon Natural cement mortars have not positively confirmed the judgment reached by nearly all engineers experienced in construction in freezing weather. Occasional tests are recorded in which such mortars, especially when subjected to a uniformly cold temperature and then suddenly thawed, have attained full strength, but these are insufficient to warrant the use of any except Portland cements when frost is likely to occur before the mortar is thoroughly dry.

The prevention of injury from frost in certain cements may be due, at least in part, to the internal heat produced when setting. In the interior of a large mass, some cements, especially high grade Portlands, attain a high temperature. (See p. 130.)

Chapter V. reprinted by permission from "Concrete Plain and Reinforced" by Taylor & Thompson:

CLASSIFICATION OF CEMENTS.

From an engineering standpoint, limes and cements may be classified as

Portland cement.
Natural cement.
Puzzolan cement.
Hydraulic lime.
Common lime.

Typical analysis of each are presented in the following table. The composition of Natural cement, even different samples of the same brand, is so extremely variable that their analyses cannot be regarded as characteristics of locality.

Typical Analysis of Cements.

	Portland Cement		Natural Cement							Common Lime	
			American		Engl'h	French					
	Lehigh Valley[1] (mixed rock)	Western[2] (marl and clay)	Eastern Rosendales[3]	Western Louisvilles[3]	Roman[4]	Vassy[5]	Grappiers[6]	Puzzolan Cement[7]	Hydraulic Lime (Le Tiel)[8]	Lime[9]	Magnes'n Lime[10]
Silica SiO_2	21.31	21.93	18.38	20.42	25.48	22.60	26.5	28.95	21.70	1.03	1.12
Alumina Al_2O_3	6.89	5.98	15.20	4.76	10.30	8.90	2.5	11.40	3.19	1.27	0.68
Iron Oxide Fe_2O_3	2.53	2.35		3.40	7.44	5.30	1.5	0.54	0.66		
Calcium Oxide CaO	62.89	62.92	35.84	46.64	44.54	52.69	63.0	50.29	60.70	97 02	58.51
Magnesian Oxide MgO	2.64	1.10	14.02	12.00	2.92	1.15	1.0	2.96	0.85	0.68	39.69
Sulphuric Acid SO_3	1.34	1 54	0.93	2.57	2.61	3.25	0.5	1.37	0.60		
Loss on Ignition	1.39	2.91	3.73	6.75	3.68	6.11	5.0	3.39	12.20		
Other constituents	0.75		11.46	3.74	1.46			0.30	0.10		

[1] W. F. Hillebrand, Society of Chemical Industry, 1902, Vol. XXI.
[2] W. F. Hillebrand, Journal American Chemical Society, 1903, 25, 1180.
[3] Clifford Richardson, *Brickbuilder*, 1897, p. 229.
[4] Stanger & Blount, Mineral Industry, Vol. V., p. 69.
[5] Candlot, Ciments et Chaux Hydrauliques, 1898, p. 174.
[6] Le Chatelier, Annales des Mines, September and October, 1893, p. 36.
[7] Report of the Board of U. S. Army Engineers on Steel Portland Cement, 1900, p. 52.
[8] Candlot, Ciments et Chaux Hydrauliques, 1898, p. 24.
[9] Rockland Rockport Lime Co.
[10] Western Lime and Cement Co.

PORTLAND CEMENT.

Portland cement is defined by Mr. Edwin C. Eckel of the U. S. Geological Survey as follows: "By the term Portland cement is to be understood the material obtained by finely pulverizing clinker produced by burning to semi-fusion an intimate artificial mixture of finely ground calcareous and argillaceous materials, this mixture consisting approximately of 3 parts of lime carbonate to 1 part of silica, alumina and iron oxide."

The definition is often further limited by specifying that the finished product must contain at least 1.7 times as much lime, by weight, as of silica, alumina, and iron oxide together.

The only surely distinguishing test of Portland cement is its chemical analysis and its specific gravity. (See pp. 64 and 65.) In the field it may often be recognized by its cold bluish gray color (see p. 113), although the color of Puzzolan and of some Natural cement is so similar that this is by no means a positive indication.

The term *Natural Portland Cement* arose from the discovery in Boulogne-sur-Mer, France, as early as 1846, of a natural rock of suitable composition for Portland cement. A similar discovery in Pennsylvania gave rise to the same term in America, but the manufacturers

soon found it necessary to add to the cement rock a small percentage of purer limestone. Since the chemical composition of Portland cement, as defined above, is substantially uniform regardless of the materials from which it is made, in the United States the terms "natural" and "artificial" are meaningless.

In France, cements intermediate between Roman and Portland are called "natural Portlands."*

Sand Cement. Sand or silica cement is a mechanical mixture of Portland cement with a pure, clean sand very finely ground together in a tube mill or similar machine. For the best grades the proportions of cement to sand are 1:1, although as lean a mixture as 1:6 has been made to compete with Natural cements. The coarser particles in any Portland cement have little cementitious value, hence if a portion of the cement is replaced by inert matter and the whole ground extremely fine, its advocates maintain that the product is scarcely inferior to the unadulterated article. As made in the United States, the mixture is ground so fine that 95 per cent of it will pass through a sieve having 200 meshes to the linear inch, and all of the 5 per cent residuum is said to be sand. In other words, all of the cement passes a No 200 sieve.

NATURAL CEMENT.

Natural cement is "made by calcining natural rock at a heat below incipient fusion, and grinding the product to powder."* Natural cement contains a larger proportion of clay than hydraulic lime, and is consequently more strongly hydraulic. Its composition is extremely variable on account of the difference in the rock used in manufacture.

Natural cements in the United States in numerous instances bear the names of localities where first manufactured. For example, Rosendale cement, a term heard in New York and New England more frequently than Natural cement, was originally manufactured in Rosendale, Ulster County, N. Y. Louisville cement first came from Louisville, Ky. The James River, Milwaukee, Utica, and Akron are other Natural cements named for localities.

The United States produces a few brands of "Improved Natural Hydraulic Cement," intermediate in quality between Natural and Portland, by mixing inferior Portland cement with Natural cement clinker.

In England the best known Natural cement is called Roman cement. Occasionally one hears the term Parker's cement, so called from the name of the discoverer in England.

LE CHATELIER'S CLASSIFICATION OF NATURAL CEMENTS.

In France there are several classes of natural cement. Mr. H. Le Chatelier† classifies Natural Cements as those obtained "by the heating of limestone less rich in lime than the limestone for hydraulic lime. They may be divided into three classes:

*Candlot's Ciments et Chaux Hydrauliques, 1898, p. 164.
*Professional Papers, No. 28, U. S. Army Engineers, p. 33.
†Procedes d'Essai des Materiaux Hydrauliques, Annales des Mines, 1893.

"Quick-setting cements, such as Vassy and Roman (Ciments a prise rapide, Vassy, romain);

"Slow-setting cements (Ciments a prise demi-lente);

"Grappiers cement (Ciments de grappiers).

"**Vassy Cements** are obtained by the heating of limestone containing much clay, at a very low temperature, just sufficient to decarbonate the lime. They are characterized by a very rapid set, followed afterwards by an extremely slow hardening, much slower than that of Portland cements."

"They differ from Portland cements by containing a much higher percentage of sulphuric acid, which appears to be one of their essential elements, and a much lower percentage of lime.

"**Slow Setting Cements,** by the high temperature of calcination, approach Portland cements, but the natural limestones never possess the homogeneity of artificial mixtures, so that it is impossible to avoid in these cements the presence of a large quantity of free lime." The composition of these products varies from that of the Vassy cements to that of the real Portlands.

"**Grappiers Cements** are obtained by the grinding of particles which have escaped disintegration in the manufacture of hydraulic limes. These grappiers are a mixture of four distinct materials, two of which, completely inert, are unburned limestone and the clinkers formed by contact with the siliceous walls of furnaces, and two of which, strongly hydraulic, are unslacked lime and true slow-setting cement. It is necessary that the latter should predominate in the grappiers for their grinding to give a useful product. The grappier of cement is obtained regularly only by the heating of a limestone but slightly aluminous and containing about three equivalents of carbonate of lime for one of silica; its production necessitates a heating at high temperature.

"These grappiers cements are even more apt to contain free lime than the Natural cements of slow set which are obtained by the heating of limestone containing much more alumina. Because of their constitution, also, the grappiers cements may vary greatly in composition since they are produced by the grinding of a mixture of grains of cement and of various inert materials. The cement grains have very nearly the composition of tricalcium silicate (SiO_2 3 CaO)."

PUZZOLAN OR SLAG CEMENT.

Puzzolan cement is the product resulting from mixing and grinding together in definite proportions slaked lime and granulated blast furnace slag or natural puzzolanic matter (such as puzzolan, santorin earth, or trass obtained from volcanic tufa).

The ancient Roman cements belonged to the class of Puzzolans. They were made by mechanically mixing slaked lime with natural puzzolana formed from the fusion of natural rock found in the volcanic regions of Italy. In Germany, trass, a volcanic product related to Puzzolan, has been used with lime in the manufacture of cements.

Blast furnace slag is essentially an artificial puzzolana, formed by the combustion in a blast furnace, and the puzzolan or slag cements of the United States are ground mixtures of granulated blast furnace slag, of special composition, and slaked lime.

A Board of Engineers officers, U. S. A., presented in 1901 the following conclusion, * based, undoubtedly, on the exhaustive studies upon the subject made by a previous Board† having the same chairman, Major W. L. Marshall:

This term (slag or Puzzolan cement) is applied to cement made by intimately mixing by grinding together granulated blast-furnace slag of a certain quality and slaked lime, without calcination subsequent to the mixing. This is the only cement of the Puzzolan class to be found in our markets (often branded Portland), and as true Portland cement is now made having slag for its hydraulic base, the term "slag cement" should be dropped and the generic term Puzzolan be used in advertisements and specifications for such cements.

Puzzolan cement made from slag is characterized physically by its light lilac color; the absence of grit attending fine grinding and the extreme subdivision of its slaked lime element; its low specific gravity (2.6 to 2.8) compared with Portland (3 to 3.5); and by the intense bluish green color in the fresh fracture after long submersion in water, due to the presence of sulphides, which color fades after exposure to dry air.

The oxidation of sulphides in dry air is destructive of Puzzolan cement mortars and concretes so exposed. Puzzolan is usually very finely ground, and when not treated with soda sets more slowly than Portland. It stands storage well, but cements treated with soda to quicken setting become again very slow setting, from the carbonization of the soda (as well as the lime) element after long storage.

Puzzolan cement properly made contains no free or anhydrous lime, does not warp or swell, but is liable to fail from cracking and shrinkage (at the surface only) in dry air.

Mortars and concretes made from Puzzolan approximate in tensile strength similar mixtures of Portland cement, but their resistance to crushing is less, the ratio of crushing to tensile strength being about 6 to 7 to 1 for Puzzolan, and 9 to 11 to 1 for Portland. On account of its extreme fine grinding Puzzolan often gives nearly as great tensile strength in 3 to 1 mixtures as neat.

Puzzolan permanently assimilates but little water compared with Portland, its lime being already hydrated. It should be used in comparatively dry mixtures well rammed, but while requiring little water for chemical reactions, it requires for permanency in the air constant or continuous moisture.

Puzzolanic material has been suggested by Dr. Michaelis, of Germany, and Mr. R. Feret, of France (see Chapter XVIII), as a valuable addition to Portland cement designed for use in sea water.

*Professional Papers No. 28, p. 28.
†Report of the Board of U. S. Army Engineers on Steel Portland Cement, 1900, p. 52.

HYDRAULIC LIME.

The hydraulic properties of a lime,—its ability to harden under water,—are due to the presence of clay, or, more correctly, to the silica contained in the clay. Hydraulic lime is still used to quite an extent in Europe, especially in France, as a substitute for hydraulic cement. The celebrated lime-of-Teil of France is a hydraulic lime.

Mr. Edwin C. Eckel states * that theoretically the proper composition for a hydraulic limestone should be calcium carbonate 86.8% silica 13.2%. The hydraulic limestones in actual use, however, usually carry a much higher silica percentage, reaching at times to 25%, while alumina and iron are commonly present in quantities which may be as high as 6%. The lime content of the limestones commonly used varies from 55% to 65%."

Although the chemical composition of hydraulic lime is similar to Portland cement, its specific gravity is much lower, lying between 2.5 and 2.8.†

In the manufacture of hydraulic lime the limestone of the required composition is burned, generally in continuous kilns, and then sufficient water is added to slake the free lime produced so as to form a powder without crushing.

COMMON LIME.

The commercial lime of the United States is "quicklime," which is chiefly calcium oxide (CaO).

Lime is now manufactured by a continuous process. Limestone of a rather soft texture, so as to be as free as possible from silica, iron and alumina, is charged into the top of the kiln which may be, say, 40 ft. high by 10 ft. in diameter. The fuel is introduced into combustion chambers near the foot of the shaft, and the finished product is drawn out from time to time through another opening in the bottom of the shaft. The temperature of calcination may range from 1400° Fahr. (760° Cent.) to, at times, 2,000° Fahr. (1,090° Cent.). The product (see analysis, p. 47), in ordinary lime of the best quality, is nearly pure calcium oxide (CaO). Upon the addition of water the lime slakes, forming calcium hydrate (CaH_2O_2), and, with the continued addition of water increases in bulk to twice or three times the original loose and dry volume of the lump lime as measured in the cask. In this plastic condition it is termed by plasterers "putty" or "paste."

The setting of lime mortar is the result of three distinct processes which, however, may all go on more or less simultaneously. First, it dries out and becomes firm. Second, during this operation, the calcic hydrate, which is in solution in the water of which the mortar is made, crystalizes and binds the mass together. Hydrate of lime is soluble in 831 parts of water at 78° Fahr; in 759 parts at 32° and in 1136 parts at 140°. Third, as the per cent. of water in the mortar is reduced and reaches five per cent., carbonic acid begins to be absorbed from the

***American Geologist*, March, 1902, p. 152.
†Candlot s Ciments et Chaux Hydraulique, 1898, p 26.

atmosphere. If the mortar contains more than five per cent. this absorption does not go on. While the mortar contains as much as 0.7 per cent. the absorption continues. The resulting carbonate probably unites with the hydrate of lime to form a sub-carbonate, which causes the mortar to attain a harder set, and this may finally be converted to carbonate. The mere drying out of mortar, our tests have shown, is sufficient to enable it to resist the pressure of masonry, while further hardening furnishes the necessary bond.*

Magnesian Limes evolve less heat when slaking, expand less, and set more rapidly than pure lime. A typical analysis is given an page 47.

Hydrated Lime is a powdered slaked lime (calcium hydrate). It is manufactured by treating finely ground common lump lime with water of a certain temperature, and then cooling and screening it through a very fine screen.

*The author's are indebted to Mr. Clifford Richardson for this paragraph.

FINISHING SURFACES OF REINFORCED CONCRETE.

Objections are often heard as to the unsightly appearance of concrete buildings when finished. With a little care concrete structures may be made as beautiful to the eye as buildings built of any other material.

The following chapter, XVII, reprinted from Buel & Hill's volume, "Reinforced Concrete," will be found most interesting on this subject, dealing with the numerous finishes which may be applied at very little cost.

CHAPTER XVII.—FACING AND FINISHING EXPOSED CONCRETE SURFACES.

The difficulty of securing an even-grained surface of uniform color on concrete work is one of the most annoying which builders of such work have to overcome. Concrete work is subject to various sorts of surface imperfection, but the two most common imperfections are roughness or irregular surface texture and variability of color or discoloration. Either of these imperfections is capable of disfiguring an otherwise sightly structure, and the task of avoiding them is one which warrants serious attention from those undertaking work in reinforced concrete. Unfortunately practice has not settled upon a solution of the problem, hence its consideration here is rather a record of experience than a set of instructions which can be followed with the certainty that successful results will ensue.

Causes of Roughness and Discoloration.—There are several conditions which may result in a concrete surface of uneven texture and with mechanical roughnesses, such as projections, bulges, ridges, pits, bubble-holes, and scales. One of these is imperfections in the molds. The use of rough lagging of uneven thickness and with open cracks and allowing the forms to become distorted and warped are certain to leave their impress upon the plastic concrete in the form of ridges, tongues, and bulges. Failure to pack the concrete filling tightly and evenly against the mold will result in rough places. Lack of homogeneity in the concrete is another prolific cause of variation in the surface texture of concrete work. This lack of homogeneity may result from failure to mix the concrete materials thoroughly and evenly in the first place, or the segregation of the coarse and fine parts of the mixture during its deposition and ramming into place. In both cases the result is a material of alternate coarse and fine texture. Dirt or cement adhering to the molds will leave pits in the concrete surface, and the pulling away of the concrete in spots when it adheres to the molds when they are removed will cause similar roughness.

Variations in the color of concrete surfaces probably result from a variety of causes. Some of these are obvious and others are difficult to determine with any exactness. Roughness or uneven surface texture is a common cause of variation in color, since the alternate rough

and smooth parts weather differently and collect and hold dirt and soot in different degrees. Another cause of variation in color is the use of different cements in adjacent parts of the surface work. No two cements are of exactly the same shade of color, and the concrete made of them partakes of this variation. In a similar manner sand of different shades of color or of different degrees of cleanliness will cause a cloudy and streaky appearance in concrete . Dirt adhering to the molds will frequently stain the adjacent concrete surface.

Even when the smoothness of the surface is satisfactory, however, and when there is no criticism possible as to the kind and quality of the aggregates, their deposition and the cleanliness with which the work is done, concrete surfaces frequently vary in color and have a cloudy light and dark appearance. In many cases there seems to be good reason for attributing this to the leaching out of lime, compounds and their deposition in the form of an efflorescence on the concrete surface. The extent of this efflorescence varies; at times the deposit is so thin as merely to give a lighter shade to the places where it appears, but it will often form an encrustation of considerable body and thickness which may be readily scraped of as a white or yellowish-white powder. The nature of this discoloration and the preventive and remedial treatments which have been practiced in its cure are discussed more fully in a succeeding paragraph.

Construction of Forms.—Very slight imperfections in the face of the forms against which the concrete is molded are sufficient to leave an unsightly impression on the plastic mixture when it hardens. Even the grain of smoothly dressed timber will show on the surface of concrete which has been deposited with a mortar facing. It is very difficult to construct forms so that they will not leave slight impressions of this character, and it is generally better not to attempt the task in any but exceptional instances. In these a straight-grained, smoothly dressed timber, with its pores filled with soap or paraffine well rubbed in, or a rougher timber covered with sheet metal, can be used. Generally speaking, all has been done that is practicable so far as the forms are concerned when the face-lagging is kept true to surface and has close-fitting joints. Grain-marks and similar minor impressions of the forms can usually be eliminated by rubbing the surface or floating it with grout, at less cost, than by attempting to perfect the molds beyond a reasonable measure. In fact many engineers experienced in concrete work prefer not to attempt to secure particularly perfect finish in the forms, but to dress the entire surface by some style of tooling or rubbing process after the forms have been removed. The most apparent imperfection in concrete surfaces is usually the joint-marks of the lagging-boards. These may be due either to slight differences in the thickness of adjoining boards or to open joints. The remedy for the first cause is obvious, but it is not so easy to insure

smooth, tight joints and keep them smooth and tight when the boards swell from the moisture absorbed from the wet concrete. One of the most successful forms of joint is that shown by the sketch Fig. 78. In this construction the wedge edge presses into the edge of the adjoining board without distorting or bulging the lagging. Pointing the joints with hard soap or putty, packing them with oakum and covering them with pasted strips of cloth, are other means which have been practiced for preventing joint-marks on the concrete. A method of eliminating grain-marks, which was used with success in constructing piers of the Frazer River Bridge in British Columbia, consisted in covering the tightly laid matched lagging with gloss oil and then blowing sand into the oil with hand-bellows.

FIG. 78.

Mortar or Grout Facing.—One of the most frequently employed means for securing a smooth surface finish on concrete is to use a mortar or grout facing. This facing differs from plastering in being laid on as the concrete is deposited, thus forming a single piece with it. The thickness of mortar facing employed in practice varies from ½ in. to 3 ins., but the usual practice is to make it 1 in. or 1½ ins. thick. A facing as thick as 3 ins. is rather unnecessary waste of mortar, while one which is much less than 1 in. thick is likely to be pierced by the stones in the concrete unless great care is taken in ramming the concrete filling behind the mortar facing. A mortar or grout facing shows the impress of small roughnesses on the mold more readily than does concrete, and particular care is necessary to secure a smooth surface in the mold when the mortar facing is adopted. The composition of the facing mortar is usually specified as 1 part of Portland cement to 2 or 3 parts of sand. These ingredients are mixed rather wet, since the paste must completely fill the facing-mold, but care must be had not to have so thin a paste that the stones from the concrete behind will be pushed through it during the subsequent filling and ramming.

The following method of placing mortar facing is practiced by the Illinois Central R. R. and has gained wide adoption during the last few years. A sheet-iron plate 6 or 8 ins. wide and about 6 ft. long has riveted across it on one side 1½-in. angles spaced about 2 ft. apart. One edge of this plate is provided with handles. This device is employed as a mold for the facing and is operated in the following manner: The plate is set up against the face of the form with its angle-ribs close against the timber and its handles upward. In this position of the plate there is between it and the form an open slot 1½ ins. wide. This slot is filled with mortar which is tamped thoroughly, and immediately afterwards the concrete backing is deposited behind the plate. When this has been done the plate is withdrawn by the handles and the backing and facing are rammed together to a close bond. The mortar facing is mixed in small batches as it is needed, and no delay is permitted in placing the concrete backing, the

essential principle and purpose of the method being to secure as nearly as is possible the simultaneous construction of the backing of concrete and its facing of mortar.

Fig. 79 shows an excellent form of surface mold of the type just described. By varying the size of the angle-ribs any desired thickness of facing can be constructed, and the flare of the top edge facilitates the placing of the mortar, which is usually done with shovels. In lieu of a steel plate, use is sometimes made of a board provided with furring-strips on one side. This is a more unwieldly device than the one illustrated, and it is objectionable because of the large crevice left upon withdrawal into which the mortar facing is likely to slough and which is less easily closed and bonded by the final ramming. In constructing mortar facing with either iron or board molds perfect success is secured only at the expense of great care. The mortar must be mixed in small batches and only as needed, and it must be thoroughly rammed and churned into the facing-mold. The concrete backing must be deposited behind the mold without delay and firmly rammed against it, and finally the ramming together of the facing and backing must be thorough.

The following method of applying grout facing was employed with success in constructing the Atlantic Avenue subway for the Long Island R. R. in Brooklyn, N. Y. The concrete was deposited in 6-in. or 8-in. layers, and after ramming the concrete at the face was pushed back from the form about 1 in. with an ordinary gardener's spade and a thick grout of 1 part cement and 2 parts sand was poured into the space. The forms used were tongued and grooved yellow pine painted with paraffine paint. In this work a good surface was invariably secured when the men did their work faithfully, but any carelessness on their part evidenced itself in a rough spot when the forms were removed. As an indication of the susceptibility of mortar facing in taking impressions from the forms, it may be noted that even with the dressed and paraffined lagging the grain of the wood was shown perfectly on the mortar facing.

Finishing Mortar Facing.—When mortar or grout facing is employed as described in the preceding paragraphs the slightest imperfections in the grain of smoothly dressed wood is clearly impressed on the plastic material. There will also be occasional rough spots, pittings, or bubble-holes even with the most careful construction. To get rid of these some method of surface finishing must be resorted to. A number of methods have been practiced. In recent concrete culvert work on the New York Central & Hudson River R. R. an excellent surface finish was obtained by the following procedure: The forms of 2-in. dressed and matched pine, after being put in place, were painted with a coat of thin soft soap, then as the layers of concrete were brought up the face was drawn back with a square-pointed shovel, the edges of which had been hammered flat. Mortar in the proportion of 1 part cement to 2 parts sand, mixed rather wet, was then poured in along the form and the layer rammed against it. Hard

soap was used to fill openings left by joints of the lagging. When the forms were removed and while the concrete was yet "green," the surface was carefully rubbed with a circular motion, with pieces of white firebrick or briquettes of 1 cement to 1 sand, made in molds about the size of a building brick, handles being pressed in while soft. The surface was then dampened and painted with a coat of grout of 1 cement to 1 sifted sand, and this was closely followed by a final rubbing with a circular movement, using a wooden float. All edges were rounded with a Crafts edger, or with wood fillet, and the coping joints were struck with Crafts jointer.

In the specifications for concrete presented by the special committee of the Engineering and Maintenance of Way Association the following requirement for finishing was adopted:

After the forms are removed, any small cavities or openings in the concrete shall be neatly filled with mortar if necessary. Any ridges due to cracks or joints in the lumber shall be rubbed down; the entire face shall then be washed with a thin grout of the consistency of whitewash, mixed in the proportion of 1 part of cement to 2 parts of sand. The wash should be applied with a brush.

In the extensive concrete construction of the Aurora, Elgin & Chicago R. R. the exposed surfaces were all finished according to the following specifications:

All walls when finished must present a smooth, uniform surface of cement mortar, and all disfigurements must be effaced, and if there are any open, porus places, they must be neatly filled with mortar of 1 cement and 2 sand, well rubbed in, which finishing must be done immediately upon the removal of the forms. Compensation for all labor and material required in such finishing, including the mortar facing when required, with the finishing of bridge seats and other parts, is included in the price per cubic yard for concrete work.

Mr. Edwin Thacher, in his general specifications for concrete-steel requires the following surface finish:

For plain flat surfaces, the concrete may be rammed directly against the molds, and, after the molds have been removed, all exposed surfaces shall be floated to a smooth finish with semi-liquid mortar, composed of 1 part cement and 2 parts of fine, sharp sand, care being taken that no body of mortar is left on the face, sufficient only being used to fill the pores and give a smooth finish.

A very effective finish is obtained by etching the mortar facing with acid. The method consists of using a facing mortar composed of Portland cement and finely crushed stone, the kind of stone depending upon the appearance desired. Thus any shade of red or gray granite, sandstone, etc., can be obtained, and special effects can be obtained by the use of sand, pigments, etc., in the mixture. This mortar is composed of about 1 part Portland cement to 2 or 3 parts of the finely crushed stone. The exposed surfaces are then treated by chemical or mechanical means to remove the cement matrix at the face, leaving

the granular particles of stone partly exposed. In general this is done by washing the surface with a weak acid solution, then with clean water, and finally with an alkiline solution to neutralize any effects of the acid. In the finished work it is difficult to detect that the material is not natural stone, except by close inspection. The stone is crushed to pass through a sieve of 10 to 30 meshes per square inch according to the character of finish desired, and enough water is used to make a soft plastic mixture.

Plastering.—Plastering as a method of finishing concrete surfaces deserve mention for the purpose alone of calling a warning against its adoption. It is practically impossible to apply mortar in thin layers to a concrete surface and make it adhere for any length of time, and when it once begins to scale off the result is a surface many times worse in looks than the unfinished concrete that it was intended to render more sightly.

Pebble Dash Facing.—An effective surface finish for certain classes of concrete work can be secured by using large rounded pebbles in place of the usual aggregate for the surface layer of concrete, and then, while the concrete is soft, removing the mortar between the pebbles by wire brushing until approximately half the pebbles are exposed. The following specification for this style of facing was employed in constructing a small concrete road-bridge in the National Park at Washington, D. C.:

The concrete, which will be in the exterior faces of the bridge and the parapet walls for a thickness of 18 ins., will be made of gravel and rounded stone varying in the concrete below the belting course between 1½ and 2 ins. in their smallest diameters. This gravel will be mixed in the concrete as aggregate instead of broken stone. The mixture will consist of 1 part Portland cement, 2 parts sand, and 5 parts of aggregate. The parapet walls will be made in a similar manner, with the aggregate composed of gravel not exceeding 1 in. in its smallest diameter. When the forms are removed the cement and sand must be brushed from around the face of the gravel with steel brushes, leaving approximately half of the gravel exposed.

In this work it was found by test that at the age of 12 hours the concrete was not sufficiently set to hold the pebbles from being torn out by the brushing, and that at the age of 36 hours it was too hard to permit the brushing, to remove a sufficient depth of mortar without undue labor. At 24 hours' age the brushing proved most successful.

Tooled Surfaces.—A method of finishing concrete surfaces which is preferred by many experienced engineers is to dress the concrete after it has hardened by means of hammers or pointed chisels. The process is exactly analogous to stone dressing, and any of the forms of finish employed for cut stone can be employed equally well for concrete. In connection with tooled surfaces it is common to mold the concrete to represent ashlar masonry by means of horizontal and vertical V-shaped depressions formed as shown by Fig. 80. This style of finish has been extensively employed by Mr. E. L. Ransome, who gives the following directions for securing it: In imitating rough-

dressed work the mold is removed from the concrete while it is yet tender, and with small light picks the face is picked over with great rapidity, an ordinary workman finishing about 1,000 square feet per day. For imitations of finer-tooled work the concrete should be left to harden longer before being spalled or cut, and the work should be done with a chisel. Most natural stone and especially granite makes excellent material for the face, but ordinary gravel will do. Whatever is used, let it be uniform in color and of even grade. When a very fine and close imitation of a natural stone is required take the same stone, crush it and mix it with cement colored to correspond. The finer the stone is crushed the nearer the resemblance will be upon close inspection; but for fine work it is generally sufficient to reduce the stone to the size of buckshot or fine gravel.

Masonry Facing.—A facing of masonry is often employed on reinforced-concrete arch bridges, and is a very satisfactory solution of the problem of surface finish for such structures. Masonry facing may be of any style of stonework which is used for true masonry arches, and coursed ashlar, random rubble, and boulder masonry facings have all been employed. Exactly the same care should be exercised in selecting stones and laying them up into arch ring and wall, cornice and parapet, as if the structure were entirely of masonry. Beyond this the most important feature to be observed is close bonding of the masonry facing to the concrete backing. To insure this there should be a liberal use of stretchers reaching well into the backing, and these can be supplemented with metal cramps to the advantage of the work in many instances. For facing the arch ring the stones should be cut to true voussoir shape, and laid quite as perfectly as if they were a part of a true voussoir arch ring. The soffit of the arch ring is not stone-faced. In place of stone a brick facing may be employed.

The following specifications for stone and brick facing, which were prepared by Mr. Edwin Thacher, M. Am. Soc. C. E., to control work conducted by him, give a fair idea of the requirements of high-class work of this character:

Stone Facing.—If stone facing is used, the ring stones, cornices, and faces of spandrels, piers, and abutments shall be of an approved quality of stone. The stone must be of a compact texture, free from loose seams, flaws, discolorations, or imperfections of any kind, and of such a character as will stand the action of the weather. The spandrel-walls will be backed with concrete, or rubble masonry, to the thickness required. The stone facing shall in all cases be securely bonded or clamped to the backing. All stone shall be rock-faced with the exception of cornices and string courses, which shall be sawed or bush-hammered. The ring stones shall be dressed to true radial lines, and laid in Portland cement mortar, with ¼ in. joints. All other stones shall be dressed to true beds and vertical joints. No joint shall exceed ½ in. in thickness and shall be laid to break joints at least 9 ins. with the course below. All joints shall be cleaned, wet, and neatly pointed. The faces of the walls shall be laid in true lines, and to the dimensions given on plans, and the corners shall have a

chisel draft 1 in. wide carried up to the springing lines of the arch, or string course. All cornices, moldings, capitals, keystones, brackets, etc., shall be built into the work in the proper positions and shall be of the forms and dimensions shown on plans.

Brick Facing with Concrete Trimmings.—The arch rings, cornices, string courses, and quoins shall be concrete-faced as described above, the arch rings and quoins being marked and beveled to represent masonry. The piers, abutments, and spandrels shall be faced with vitrified brick, as shown on plans. The brick facing shall be plain below the springing lines of the arches, and rock-faced above these lines. All rock-faced brick shall be chipped by hand from true pitch lines. All brick-facing shall be bonded as shown on plans, at least one-fifth of the face of the wall being headers. The brick must be of the best quality of hard-burned paving brick, and must stand all tests as to durability and fitness required by the engineer in charge. The bricks must be regular in shape and practically uniform in size and color They shall be free from lime and other impurities; shall be free from checks or fire cracks, and as nearly uniform in every respect as possible; shall be burned so as to secure the maximum hardness; so annealed as to reach the ultimate degree of toughness ;and be thoroughly vitrified so as to make a homogeneous mass.

The backing shall be carried up simultaneously with the face work, and be thoroughly bonded with it.

The use of boulder facing will ordinarily be limited to structures of special character, and its success will depend very largely upon the care with which the stones are selected, their size, and their arrangement in the structure. In constructing a boulder-faced concrete arch at Washington, D. C., the following requirements were specified for the facing:

The term boulder here is meant to cover loose rock, which shall be hard, durable, and of a quality to be approved by the engineer, whose edges have become weathered or water-worn, or both, and are more or less rounded. It is the intention to obtain a decidedly rustic effect on the facing, and to that end extreme care must be taken in the selection of the stones, and only mechanics who show an aptitude for this class of work shall be employed. No tool marks or fresh fractures will be allowed on the showing faces.

The boulder face of such stone shall project at least 2 ins. beyond the neat lines of the bridge, and this projection shall not exceed 15 ins., nor shall it be greater than one-half the least horizontal dimension of the stone. All joints shall be scraped and brushed clear of mortar to the depth indicated by the engineer. The mortar shall consist of 1 part Portland cement and 2 parts sand. The backs of all boulders shall be plastered with a layer of mortar as specified, at least ¼ in. thick, immediately before ramming the concrete against them.

The arch-stones shall have a depth of between 3 and 4 ft., a width of not less than 18 ins., nor more than 36 ins.; all dimensions to be measured exclusive of the projections beyond the neat lines. The joints shall be dressed so as not to exceed 1½ ins. at any point for at least two-thirds their depth and two-thirds their length, and as much more as the stones will admit. Each arch-stone shall be cramped to the adjacent steel girder by means of a wrought-iron cramp made from ¾ × ⅜-in. bar, the cramps to reach at least 2 ins. into each boulder, to be well cemented into them, and securely cramped to the top of the girder. The outside girders shall be cramped to the adjacent girders by 10 wrought-iron cramps made from ¾ × ⅜-in. bar (in construction we used ¾-in., as it bent cold without fracture).

No dressing will be required on the stones used in abutments, spandrels, and wing walls of the work, but only well-shaped boulders, laid on their broadest bed, will be allowed. Dressing will be permitted on such stones as cannot be properly bedded without it. The parapet walls will be a continuation of the spandrel and wing walls. The boulder stone must reach entirely through the wall.

Cast Concrete Slab Veneer.—In constructing the arch bridge at Soissons, France, which is described on p. 244, the faces of the arch-ribs and the spandrel facing were formed of slabs of concrete-steel molded separately and set in place like stone veneer with the remainder of the concrete forming a backing. An essentially similar construction was employed in Chicago, Ill., in 1902, in constructing a number of recreation buildings in one of the city parks. In the last example mentioned the slabs were cast face down in wooden molds; the mode of procedure being as follows:

A layer of mortar composed of 1 part cement and 2 or 3 parts of finely crushed stone was first placed in the bottom of the mold to a depth of from ½ in. to 1 in.; on this bed of mortar a 1-2-4, concrete, with ½ to ¾ in. stone, was placed to the thickness desired and carefully rammed. After hardening, the blocks were removed from the molds and set aside to season until they were placed in the structure.

The construction of the slab veneer for the Soissons Bridge was as follows: For molding the arch-rib facing a smooth level platform or pavement of concrete was constructed on an adjacent level piece of ground. This molding platform was large enough to permit the arch-ribs to be delineated to full size on its surface. To prepare the mold the platform was covered smoothly with gunny cloth held down by battens, which also served to outline the extrados and intrados of the arch-rib. Radical strips of wood were then placed to divide the mold into voussoir-like sections. A thin bed of mortar was placed on the bottom of the mold and on this was laid four reinforcing-bars, one near and parallel to each edge of the voussoir being molded, so as to intersect at the corners. Under these bars at several points wire stirrups were looped with their fine ends projecting upward. The metal was then covered with a rich concrete of fine stone laid on the mortar-bed and compacted so that the total thickness was about 2 ins. When hardened, the product of the mold was a set of voussoir-shaped slabs with smooth faces and edges and a rough back with a number of projecting wires. In construction these facing slabs were set in place with mortar joints and backed with concrete. For the spandrel-wall facing the slabs were cast in rectangular molds in exactly the same manner. The engineers of the Soissons Bridge remark that the use of this cast concrete veneer enabled a considerable reduction of expense for forms and assured a surface finish of pleasing appearance.

Moldings and Ornamental Shapes.—The finishing of concrete structures in many instances comprehends the construction of moldings and ornamental shapes for cornices, corbels, medallions, key-stones, and other architectural parts. These may either be molded in place

by suitable construction of the stationary forms or they may be cast separately in portable molds and set in place in the structure as would be cut stone. Panels of simple form or plain cornice moldings can usually be molded in place without great trouble and expense, but in constructing corbels, complicated moldings, balusters, etc., particularly where one pattern is duplicated a number of times, time and expense will usually be saved by casting them separately or in sections, and afterwards erecting the separate pieces in the structure.

The casting of ornamental shapes in concrete may be accomplished either in sand-molds or in rigid molds of wood, metal, or plaster of Paris. Some very handsome work has been recently performed by sand-molding. The mode of procedure followed in making concrete castings in sand varies somewhat in practice, but it is substantially as follows: A pattern of the shape to be cast is first made in wood and to the exact size required, since no allowance for shrinkage is necessary. The pattern is then molded in sand in flasks exactly as is done in casting iron. The mixture used usually consists of cement and finely crushed stone of about the consistency of cream, and this is poured into the mold by means of a funnel and T pipe. The excess water in the mixture soaks into the sand and serves to keep the casting moist during setting. Generally the casting is left in the mold for three or four days, and is then removed and the projecting fins, if any, are cut off. The cast stone may be used immediately in the work, but it is preferable to let it season and harden for a fortnight or more before using. The product of these sand-molds has an unusually attractive surface texture. Sand-molding is particularly advantageous when balusters, corbels, medallions, and intricate moldings have to be cast, but for plain cornices and facing slabs it is generally as cheap and convenient to use wooden forms.

Efflorescence.—The leaching out of certain lime compounds and their deposition on the surfaces of concrete work are quite frequently the cause of the uneven color of such surfaces. In relation to this source of discoloration Mr. Clifford Richardson, Director of the New York Testing Laboratory, says:

It is primarily due to variations in the amount of water in the mortar of which the cement is composed. It will be readily understood that when any excess of water is used, segregation of the coarse and fine particles will take place, with a resulting difference in color. When a large amount of water is used the concrete is more porous and the very considerable percentage of free lime liberated from the Portland cement in the course of setting is more readily brought to the surface at such point. . . . The amount of water in a concrete, the face of which is to be exposed, should be neither too small nor too large, but such a concrete should certainly not be dry or the exposed face will be honeycombed. . . . Where the greatest care is used as to the amount of water added to the mortar and to prevent its loss, and where separation of the mortar from the broken stone is carefully avoided in depositing the concrete and in ramming it, the exposed surface, after the removal of the molds, is fairly uniform in color. . . . A more uniform color will always be obtained when some puzzolanic material is ground in with the cement such as slag or tross. This

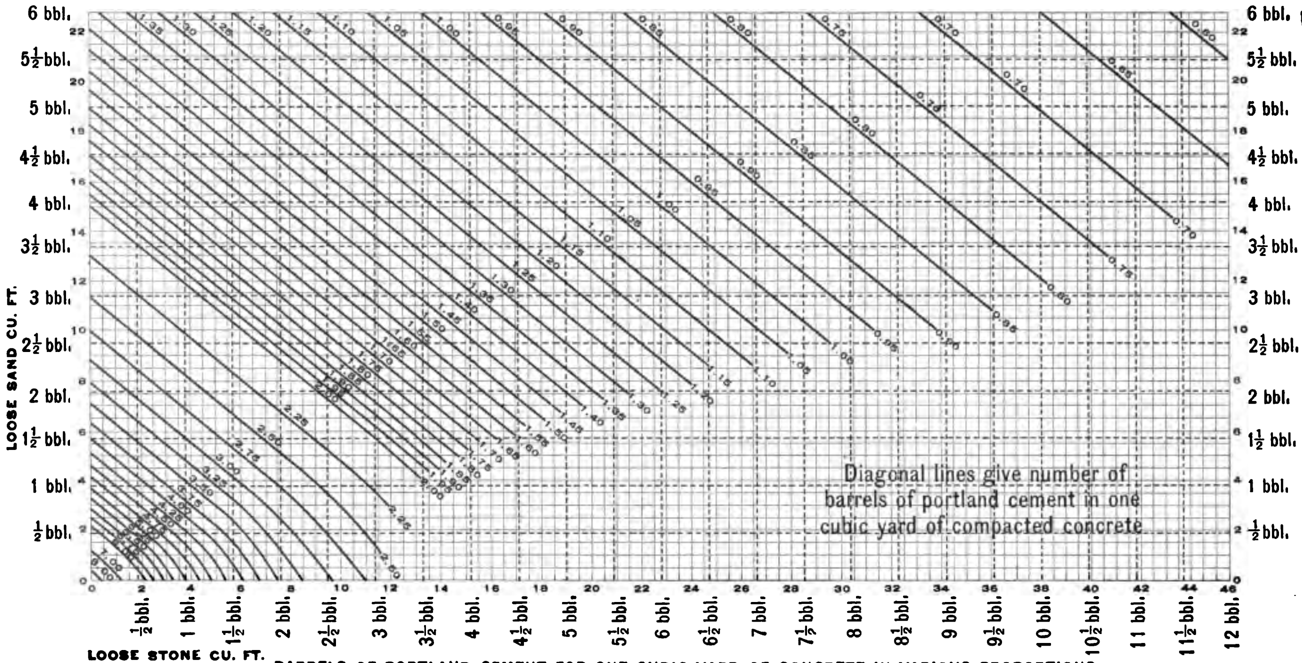
hydrated silicious material combines with the lime which has been liberated and prevents it washing out on the surface. . . . Exactness in the amount of water used in the concrete, when the elimination of the stain caused by the free lime is considered desirable, the addition of some substance containing silica in an active form are the two steps to be taken to produce a concrete surface which should present a uniform color and a pleasing appearance.

The measures whose adoption are recommended in the quotation just made are designed to prevent the occurrence of efflorescence by adopting certain precautions in the materials and workmanship of the original construction. Their adoption, however, if it gives the success that Mr. Richardson anticipates, is obviously the way to get at the root of the trouble, but such action involves a degree of skill and watchfulness in constructing concrete work which is difficult of attainment under ordinary conditions of engineering construction, and which if attained will add materially to the cost of construction. They have the further objection that a special mixture of cement is required about which our information is not entirely certain. In default of preventive measures, which recommend themselves to general use, the engineer who encounters the trouble of efflorescence must overcome it by remedial measures. There are a number of these available. The most practical ones are the washing of the discolored surfaces by solution, which will remove the incrustation, or the removal of the original surface by dressing it down with hammers or tooling or some sort.

The manner of dressing down concrete surfaces to eliminate surface imperfections is discussed in a previous paragraph. The following account of the method of cleaning a concrete-steel bridge at Washington, D. C., gives instructive data as to this mode of procedure: The bridge in question had a mortar facing and after this was completed a heavy rain caused the entire north facade to become discolored by efflorescence. This discoloration was not uniform, but in streaks and blotches of a white color, which after weathering a short time turned into a dirty yellow. To clean the bridge trial was first made of water and wire brushes, but after a little work this method was considered impracticable owing chiefly to its cost, which was estimated at $2.40 per square yard. Washes of dilute hydrochloric acid, of dilute acetic acid, and of dilute oxalic acid were then tried in conjunction with ordinary scrubbing-brushes. The hydrochloric-acid wash proved the best, and the acetic-acid wash came next in efficiency. The wash finally adopted consisted of a solution of 1 part hydrochloric acid and 5 parts water. This was applied vigorously with scrubbing-brushes, water being constantly played on the work with a hose to prevent the penetration of the acid. One house-cleaner and five laborers were employed on the work, which cost 60 cents per square yard. This high cost was due largely to the difficulty of cleaning the balustrades; it was estimated that the cost of cleaning the spandrel- and wing-walls did not exceed 20 cents per square yard. The cleaning was thoroughly satisfactory. Some of the flour removed by the brushes was analyzed and found to be silicate of lime.

TABLES OF QUANTITIES OF MATERIALS.

(Reprinted by permission from Taylor & Thompson's "Concrete, Plain and Reinforced," pages 228 to 235.)



BARRELS OF PORTLAND CEMENT FOR ONE CUBIC YARD OF CONCRETE IN VARIOUS PROPORTIONS.

BASED ON STONE HAVING 45% VOIDS

FIG. 77. (See important rules below, also examples on page 226, and formula (7) on page 224.)

1. **Dotted cross section lines** represent barrels or parts of sand and stone to one barrel (4 bags) Portland cement weighing 376 lbs. and measuring (assumed) 3.8 cu. ft.
2. **Full cross section lines** represent cubic feet of sand and stone to one barrel (4 bags) Portland cement.
3. **Diagonal lines** represent number of barrels of Portland cement in one cubic yard of compacted concrete.
4. **To find number of cubic yards of sand or stone** per cubic yard of concrete, multiply number of barrels cement, as above, by 0.141 times the number of parts of sand or stone.
5. **To find number of cubic feet of concrete,** in any proportions, made from one barrel of cement, divide 27 by the number of barrels of cement per cubic yard, obtained as above.

VOLUME OF PLASTIC MORTAR MADE FROM DIFFERENT PROPORTIONS OF CEMENT AND SAND.

QUANTITIES OF MATERIALS PER CUBIC YARD. (SEE P. 227.)

Relative proportions by volume*		Volume of Compacted Plastic Mortar						Materials for 1 cu. yd. Compact Plastic Mortar Based on barrel of					
		from 1 cu. ft. Cement			from 1 bbl. Cement								
		Based on Portland Cement weighing			Based on barrel of			3.5 cu. ft.		**3.8 cu. ft.†**		4 cu. ft.	
Cement	Sand	108 lbs. per cu. ft.	**100 lbs. per cu. ft.†**	95 lbs. per cu. ft.	3.5 cu. ft.	**3.8 cu. ft.†**	4 cu. ft.	Packed Cement	Loose Sand	**Packed Cement**	**Loose Sand**	Packed Cement	Loose Sand
		cu. ft.	**cu. ft.**	cu. ft	cu. ft.	**cu ft.**	cu. ft.	bbl.	cu. yd.	**bbl.**	**cu. yd**	bbl.	cu. yd.
1	0	0.93	0.86	0.80	3.2	3.2	3.2	8.31		8.31		8.31	
1	½	1.12	1.06	1.02	3.9	4.0	4.1	6.92	0.46	6.73	0.47	6.61	0.49
1	1	1.48	1.42	1.38	5.2	5.4	5.5	5.22	0.68	5.01	0.71	4.88	0.72
1	1½	1.84	1.78	1.74	6.4	6.7	7.0	4.20	0.81	4.00	0.84	3.87	0.86
1	2	2.20	2.14	2.11	7.7	8.1	8.4	3.51	0.91	3.32	0.93	3.21	0.95
1	2½	2.56	2.50	2.47	9.0	9.5	9.9	3.01	0.98	2.84	1.00	2.74	1.01
1	3	2.92	2.86	2.83	10.2	10.9	11.3	2.64	1.03	2.48	1.05	2.39	1.06
1	3½	3.28	3.23	3.19	11.5	12.2	12.8	2.35	1.06	2.20	1.08	2.12	1.10.
1	4	3.64	3.59	3.55	12.8	13.6	14.2	2.12	1.10	1.98	1.11	1.90	1.13
1	4½	4.01	3.95	3.91	14.0	15.0	15.6	1.92	1.12	1.80	1.14	1.72	1.15
1	5	4.37	4.31	4.28	15.3	16.4	17.1	1.77	1.15	1.65	1.16	1.58	1.17
1	5½	4.73	4.67	4.64	16.6	17.7	18.5	1.63	1.16	1.52	1.18	1.46	1.19
1	6	5.09	5.03	5.00	17.8	19.1	20.0	1.52	1.18	1.41	1.19	1.35	1.20
1	6½	5.45	5.39	5.36	19.1	20.5	21.4	1.41	1.19	1.32	1.21	1.26	1.21
1	7	5.81	5.76	5.72	20.3	21.9	22.9	1.33	1.21	1.23	1.21	1.18	1.22
1	7½	6.18	6.12	6.08	21.6	23.2	24.3	1.25	1.21	1.16	1.22	1.11	1.23
1	8	6.54	6.48	6.44	22.9	24.6	25.8	1.18	1.22	1.10	1.24	1.05	1.24

NOTE.—Variations in the fineness of the sand and the cement, and in consistency of the mortar may affect the values by 10% in either direction.
*Cement as packed by manufacturer, sand loose.
†Use these columns ordinarily

QUANTITIES OF MATERIALS FOR ONE CUBIC YARD OF RAMMED CONCRETE. BASED ON A BARREL OF 3.5 CUBIC FEET.

(See important foot-notes, also p. 225)

PROPORTIONS BY PARTS			PROPORTIONS BY VOLUMES			Volume of mortar in terms of percentage of volume of stone	PERCENTAGES OF VOIDS IN BROKEN STONE OR GRAVEL														
							50%*			45%†			40%‡			30%§			20%§		
Cement	Sand	Stone	Packed Cement bbl	Loose Sand cu ft.	Loose Stone cu. ft.	%	Cement bbl.	Sand cu. yd	Stone cu. yd.	Cement bbl	Sand cu. yd.	Stone cu. yd	Cement bbl	Sand cu. yd.	Stone cu yd	Cement bbl	Sand cu. yd	Stone cu. yd.	Cement bbl	Sand cu. yd.	Stone cu. yd.
1		1	1		3.5	101	5.25		0.68	5.07		0.66	4.89		0.63	4.51		0.58	4.19		0.54
1		2	1		7.0	54	3.84		1.00	3.64		0.94	3.47		0.90	3.09		0.80	2.80		0.73
1		3	1		10.5	39				2.85		1.11	2.69		1.05	2.35		0.91	2.10		0.82
1		4	1		14.0	31										1.90		0.99	1.69		0.88
1		5	1		17.5	27										1.59		1.03	1.41		0.91
1		6	1		21.0	24										1.37		1.07	1.21		0.94
1		7	1		24.5	21													1.06		0.96
1		8	1		28.0	20													0.94		0.98
1		9	1		31.5	18													0.84		0.98
1		10	1		35.0	17													0.77		1.00
1		11	1		38.5	16													0.70		1.00
1		12	1		42.0	16													0.65		1.01
1	1	1½	1	3.5	5.2	104	3.37	0.44	0.65	3.26	0.42	0.63	3.15	0.41	0.61	2.95	0.38	0.57	2.78	0.36	0.54
1	1	2	1	3.5	7.0	78	3.02	0.39	0.78	2.89	0.38	0.75	2.78	0.36	0.72	2.58	0.33	0.67	2.41	0.31	0.62
1	1	2½	1	3.5	8.7	64	2.73	0.35	0.88	2.60	0.34	0.84	2.49	0.32	0.80	2.29	0.30	0.74	2.12	0.28	0.68
1	1	3	1	3.5	10.5	54	2.49	0.32	0.97	2.37	0.31	0.92	2.25	0.29	0.88	2.06	0.27	0.80	1.90	0.25	0.74
1	1½	2	1	5.2	7.0	95	2.64	0.51	0.68	2.55	0.49	0.66	2.46	0.47	0.64	2.30	0.44	0.60	2.16	0.42	0.56
1	1½	2½	1	5.2	8.7	78	2.42	0.47	0.78	2.32	0.45	0.75	2.23	0.43	0.72	2.07	0.40	0.67	1.93	0.37	0.62
1	1½	3	1	5.2	10.5	65	2.23	0.43	0.87	2.13	0.41	0.83	2.04	0.39	0.79	1.88	0.36	0.73	1.74	0.34	0.68
1	1½	3½	1	5.2	12.2	56	2.07	0.40	0.94	1.97	0.38	0.89	1.88	0.36	0.85	1.72	0.33	0.78	1.59	0.31	0.72
1	1½	4	1	5.2	14.0	50	1.93	0.37	1.00	1.83	0.35	0.95	1.74	0.34	0.90	1.59	0.31	0.82	1.46	0.28	0.76
1	1½	4½	1	5.2	15.7	45	1.81	0.35	1.05	1.71	0.33	0.99	1.62	0.31	0.94	1.47	0.28	0.86	1.35	0.26	0.78
1	1½	5	1	5.2	17.5	41	1.70	0.33	1.10	1.60	0.31	1.04	1.52	0.29	0.99	1.37	0.26	0.89	1.25	0.24	0.81
1	2	3	1	7.0	10.5	77	2.02	0.52	0.79	1.94	0.50	0.75	1.86	0.48	0.72	1.73	0.45	0.67	1.61	0.42	0.63
1	2	3½	1	7.0	12.2	67	1.89	0.49	0.85	1.80	0.47	0.81	1.73	0.45	0.78	1.59	0.41	0.72	1.48	0.38	0.67
1	2	4	1	7.0	14.0	59	1.77	0.46	0.92	1.69	0.44	0.88	1.61	0.42	0.83	1.48	0.38	0.77	1.37	0.35	0.71
1	2	4½	1	7.0	15.7	53	1.67	0.43	0.97	1.58	0.41	0.92	1.51	0.39	0.88	1.38	0.36	0.80	1.27	0.33	0.74
1	2	5	1	7.0	17.5	48	1.57	0.41	1.02	1.49	0.39	0.97	1.42	0.37	0.92	1.29	0.33	0.84	1.18	0.31	0.76
1	2	5½	1	7.0	19.2	44	1.49	0.39	1.06	1.41	0.36	1.00	1.34	0.35	0.95	1.21	0.31	0.86	1.11	0.29	0.79
1	2	6	1	7.0	21.0	41	1.42	0.37	1.10	1.34	0.35	1.04	1.27	0.33	0.99	1.14	0.30	0.89	1.04	0.27	0.81
1	2½	3	1	8.7	10.5	90	1.84	0.59	0.72	1.78	0.57	0.69	1.71	0.55	0.66	1.60	0.52	0.62	1.50	0.48	0.58
1	2½	3½	1	8.7	12.2	78	1.73	0.56	0.78	1.66	0.53	0.75	1.60	0.52	0.72	1.48	0.48	0.67	1.38	0.44	0.62
1	2½	4	1	8.7	14.0	68	1.63	0.52	0.85	1.56	0.50	0.81	1.50	0.48	0.78	1.38	0.44	0.72	1.28	0.41	0.66
1	2½	4½	1	8.7	15.7	61	1.55	0.50	0.90	1.47	0.47	0.86	1.41	0.45	0.82	1.29	0.42	0.75	1.20	0.39	0.70
1	2½	5	1	8.7	17.5	55	1.47	0.47	0.95	1.39	0.45	0.90	1.33	0.43	0.86	1.22	0.39	0.79	1.12	0.36	0.73
1	2½	5½	1	8.7	19.2	51	1.39	0.45	0.99	1.32	0.42	0.94	1.26	0.41	0.90	1.15	0.37	0.82	1.06	0.34	0.75
1	2½	6	1	8.7	21.0	47	1.33	0.43	1.03	1.26	0.41	0.98	1.20	0.39	0.93	1.09	0.35	0.85	1.00	0.32	0.78
1	2½	6½	1	8.7	22.7	44	1.27	0.41	1.07	1.20	0.39	1.01	1.14	0.37	0.96	1.03	0.33	0.87	0.94	0.30	0.79
1	2½	7	1	8.7	24.5	41	1.22	0.39	1.11	1.15	0.37	1.04	1.09	0.35	0.99	0.98	0.32	0.89	0.90	0.29	0.82
1	3	4	1	10.5	14.0	77	1.52	0.59	0.79	1.46	0.57	0.76	1.40	0.54	0.73	1.30	0.50	0.67	1.21	0.47	0.63
1	3	4½	1	10.5	15.7	69	1.44	0.56	0.84	1.38	0.54	0.80	1.32	0.51	0.77	1.22	0.47	0.71	1.13	0.44	0.66
1	3	5	1	10.5	17.5	62	1.37	0.53	0.89	1.31	0.51	0.85	1.25	0.48	0.81	1.15	0.45	0.75	1.07	0.42	0.69
1	3	5½	1	10.5	19.2	57	1.31	0.51	0.93	1.25	0.48	0.89	1.19	0.46	0.85	1.09	0.42	0.78	1.01	0.39	0.72
1	3	6	1	10.5	21.0	53	1.25	0.48	0.97	1.19	0.46	0.93	1.13	0.44	0.88	1.03	0.40	0.80	0.95	0.37	0.74
1	3	6½	1	10.5	22.7	49	1.20	0.47	1.01	1.14	0.44	0.96	1.08	0.42	0.91	0.98	0.38	0.82	0.90	0.35	0.76
1	3	7	1	10.5	24.5	46	1.15	0.45	1.04	1.09	0.42	0.99	1.03	0.40	0.93	0.94	0.36	0.85	0.86	0.33	0.78
1	3	7½	1	10.5	26.2	43	1.11	0.43	1.08	1.05	0.41	1.02	0.99	0.38	0.96	0.90	0.35	0.87	0.82	0.32	0.80
1	3	8	1	10.5	28.0	40	1.06	0.41	1.10	1.01	0.39	1.05	0.95	0.37	0.99	0.86	0.33	0.89	0.78	0.30	0.81
1	4	5	1	14.0	17.5	77	1.22	0.63	0.79	1.17	0.61	0.76	1.12	0.58	0.73	1.04	0.54	0.67	0.97	0.50	0.63
1	4	6	1	14.0	21.0	65	1.12	0.58	0.87	1.07	0.55	0.83	1.02	0.53	0.79	0.94	0.49	0.73	0.87	0.45	0.68
1	4	7	1	14.0	24.5	56	1.04	0.54	0.94	0.99	0.51	0.90	0.94	0.49	0.85	0.86	0.44	0.78	0.80	0.41	0.73
1	4	8	1	14.0	28.0	50	0.97	0.50	1.01	0.92	0.48	0.95	0.87	0.45	0.90	0.80	0.41	0.83	0.73	0.38	0.76
1	4	9	1	14.0	31.5	45	0.91	0.47	1.06	0.86	0.44	1.00	0.81	0.42	0.94	0.74	0.38	0.86	0.68	0.35	0.79
1	4	10	1	14.0	35.0	41	0.85	0.44	1.10	0.81	0.42	1.05	0.76	0.39	0.98	0.69	0.36	0.89	0.63	0.33	0.82
1	5	10	1	17.5	35.0	48	0.79	0.51	1.02	0.75	0.49	0.97	0.71	0.46	0.92	0.65	0.42	0.84	0.59	0.38	0.76
1	6	12	1	21.0	42.0	46	0.67	0.52	1.04	0.63	0.49	0.98	0.60	0.47	0.93	0.54	0.42	0.84	0.50	0.39	0.78

NOTE.—Variations in the fineness of the sand and the compacting of the concrete may affect the quantities by 10% in either direction.

*Use 50% columns for broken stone screened to uniform size.

†Use 45% columns for average conditions and for broken stone with dust screened out.

‡Use 40% columns for gravel or mixed stone and gravel.

§Use these columns for scientifically graded mixtures.

QUANTITIES OF MATERIALS FOR ONE CUBIC YARD OF RAMMED CONCRETE, BASED ON A BARREL OF 3.8 CUBIC FEET.

(See important foot-notes, also p. 225.)

Proportions by Parts			Proportions by Volumes			Volume of mortar in terms of percentage of volume of stone	Percentages of Voids in Broken Stone or Gravel														
							50%*			45%†			40%‡			30%§			20%§		
Cement	Sand	Stone	Packed Cement	Loose Sand	Loose Stone		Cement	Sand	Stone	Cement	Sand	Stone	Cement	Sand	Stone	Cement	Sand	Stone	Cement	Sand	Stone
			bbl.	cu. ft.	cu. ft.	%	bbl.	cu. yd.	cu. yd.	bbl.	cu. yd.	cu. yd.	bbl.	cu. yd.	cu. yd.	bbl.	cu. yd.	cu. yd.	bbl.	cu. yd.	cu. yd.
1		1	1		3.8	94	5.09		0.72	4.90		0.69	4.73		0.67	4.33		0.61	4.02		0.57
1		2	1		7.6	51	3.67		1.03	3.48		0.98	3.30		0.93	2.93		0.82	2.65		0.75
1		3	1		11.4	36				2.69		1.14	2.54		1.07	2.22		0.94	1.98		0.84
1		4	1		15.2	29										1.78		1.00	1.58		0.89
1		5	1		19.0	25										1.49		1.05	1.31		0.92
1		6	1		22.8	22										1.28		1.08	1.12		0.95
1		7	1		26.6	20													0.98		0.97
1		8	1		30.4	19													0.87		0.98
1		9	1		34.2	18													0.78		0.99
1		10	1		38.0	17													0.71		1.00
1		11	1		41.8	16													0.65		1.01
1		12	1		45.5	15													0.60		1.01
1	1	1½	1	3.8	5.7	99	3.19	0.45	0.67	3.08	0.43	0.65	2.97	0.42	0.63	2.78	0.39	0.59	2.62	0.37	0.55
1	1	2	1	3.8	7.6	75	2.85	0.40	0.80	2.73	0.38	0.77	2.62	0.37	0.74	2.43	0.34	0.68	2.26	0.32	0.64
1	1	2½	1	3.8	9.5	61	2.57	0.36	0.90	2.45	0.34	0.86	2.34	0.33	0.82	2.15	0.30	0.76	1.99	0.28	0.70
1	1	3	1	3.8	11.4	51	2.34	0.33	0.99	2.22	0.31	0.94	2.12	0.30	0.90	1.93	0.27	0.82	1.77	0.25	0.75
1	1½	2	1	5.7	7.6	93	2.49	0.53	0.70	2.40	0.51	0.68	2.31	0.49	0.65	2.16	0.46	0.61	2.03	0.43	0.57
1	1½	2½	1	5.7	9.5	76	2.27	0.48	0.80	2.18	0.46	0.77	2.09	0.44	0.74	1.94	0.41	0.68	1.80	0.38	0.63
1	1½	3	1	5.7	11.4	64	2.09	0.44	0.88	2.00	0.42	0.84	1.91	0.40	0.81	1.76	0.37	0.74	1.63	0.34	0.69
1	1½	3½	1	5.7	13.3	55	1.94	0.41	0.96	1.84	0.39	0.91	1.76	0.37	0.87	1.61	0.34	0.79	1.48	0.31	0.73
1	1½	4	1	5.7	15.2	49	1.80	0.38	1.01	1.71	0.36	0.96	1.63	0.34	0.92	1.48	0.31	0.83	1.36	0.29	0.77
1	1½	4½	1	5.7	17.1	44	1.69	0.36	1.07	1.60	0.34	1.01	1.51	0.32	0.96	1.37	0.29	0.87	1.25	0.26	0.79
1	1½	5	1	5.7	19.0	40	1.59	0.34	1.12	1.50	0.32	1.06	1.42	0.30	1.00	1.28	0.27	0.90	1.17	0.25	0.82
1	2	3	1	7.6	11.4	75	1.89	0.53	0.80	1.81	0.51	0.76	1.74	0.49	0.74	1.61	0.45	0.68	1.50	0.42	0.63
1	2	3½	1	7.6	13.3	65	1.76	0.49	0.87	1.68	0.47	0.83	1.61	0.45	0.79	1.48	0.42	0.73	1.38	0.39	0.68
1	2	4	1	7.6	15.2	57	1.65	0.46	0.93	1.57	0.44	0.88	1.50	0.42	0.84	1.38	0.39	0.78	1.27	0.36	0.72
1	2	4½	1	7.6	17.1	51	1.55	0.44	0.98	1.48	0.42	0.94	1.41	0.40	0.89	1.28	0.36	0.81	1.18	0.33	0.75
1	2	5	1	7.6	19.0	47	1.47	0.41	1.03	1.39	0.39	0.98	1.32	0.37	0.93	1.20	0.34	0.84	1.10	0.31	0.77
1	2	5½	1	7.6	20.9	43	1.39	0.39	1.08	1.31	0.37	1.01	1.25	0.35	0.97	1.13	0.32	0.87	1.03	0.29	0.80
1	2	6	1	7.6	22.8	40	1.32	0.37	1.11	1.25	0.35	1.06	1.18	0.33	1.00	1.06	0.30	0.89	0.97	0.27	0.82
1	2½	3	1	9.5	11.4	87	1.72	0.61	0.73	1.66	0.58	0.70	1.60	0.56	0.68	1.49	0.52	0.63	1.40	0.49	0.59
1	2½	3½	1	9.5	13.3	75	1.62	0.57	0.80	1.55	0.55	0.76	1.49	0.52	0.73	1.38	0.49	0.68	1.29	0.45	0.64
1	2½	4	1	9.5	15.2	66	1.52	0.54	0.86	1.46	0.51	0.82	1.40	0.49	0.79	1.29	0.45	0.73	1.19	0.42	0.67
1	2½	4½	1	9.5	17.1	60	1.44	0.51	0.91	1.37	0.48	0.87	1.31	0.46	0.83	1.20	0.42	0.76	1.11	0.39	0.70
1	2½	5	1	9.5	19.0	54	1.37	0.48	0.96	1.30	0.46	0.92	1.24	0.44	0.87	1.13	0.40	0.80	1.04	0.37	0.73
1	2½	5½	1	9.5	20.9	49	1.30	0.46	1.01	1.23	0.43	0.95	1.17	0.41	0.91	1.07	0.38	0.83	0.98	0.34	0.76
1	2½	6	1	9.5	22.8	46	1.24	0.44	1.05	1.17	0.41	0.99	1.11	0.39	0.94	1.01	0.36	0.85	0.92	0.32	0.78
1	2½	6½	1	9.5	24.7	42	1.18	0.42	1.08	1.12	0.39	1.02	1.06	0.37	0.97	0.96	0.34	0.88	0.88	0.31	0.80
1	2½	7	1	9.5	26.6	40	1.13	0.40	1.11	1.07	0.38	1.05	1.01	0.36	0.99	0.91	0.32	0.90	0.83	0.29	0.82
1	3	4	1	11.4	15.2	76	1.42	0.60	0.80	1.36	0.57	0.77	1.30	0.55	0.73	1.21	0.51	0.68	1.12	0.47	0.63
1	3	4½	1	11.4	17.1	68	1.34	0.57	0.85	1.28	0.54	0.81	1.23	0.52	0.78	1.13	0.48	0.72	1.05	0.44	0.66
1	3	5	1	11.4	19.0	61	1.28	0.54	0.90	1.22	0.52	0.86	1.17	0.49	0.82	1.07	0.45	0.75	0.99	0.42	0.70
1	3	5½	1	11.4	20.9	56	1.22	0.52	0.94	1.16	0.49	0.90	1.11	0.47	0.86	1.01	0.43	0.78	0.93	0.39	0.72
1	3	6	1	11.4	22.8	52	1.16	0.49	0.98	1.11	0.47	0.94	1.05	0.44	0.89	0.96	0.41	0.81	0.88	0.37	0.74
1	3	6½	1	11.4	24.7	48	1.12	0.47	1.02	1.06	0.45	0.97	1.01	0.43	0.92	0.92	0.39	0.84	0.84	0.35	0.77
1	3	7	1	11.4	26.6	45	1.07	0.45	1.05	1.01	0.43	0.99	0.96	0.40	0.95	0.87	0.37	0.86	0.80	0.34	0.79
1	3	7½	1	11.4	28.5	42	1.03	0.44	1.09	0.97	0.41	1.02	0.92	0.39	0.97	0.83	0.35	0.88	0.76	0.32	0.80
1	3	8	1	11.4	30.4	40	0.99	0.42	1.11	0.93	0.39	1.05	0.88	0.37	0.99	0.80	0.34	0.90	0.73	0.31	0.82
1	4	5	1	15.2	19.0	76	1.13	0.64	0.80	1.08	0.61	0.76	1.04	0.59	0.73	0.96	0.54	0.68	0.90	0.51	0.63
1	4	6	1	15.2	22.8	64	1.04	0.59	0.88	0.99	0.56	0.84	0.95	0.54	0.80	0.87	0.49	0.73	0.81	0.46	0.68
1	4	7	1	15.2	26.6	55	0.96	0.54	0.95	0.92	0.52	0.91	0.88	0.50	0.87	0.80	0.45	0.79	0.74	0.42	0.73
1	4	8	1	15.2	30.4	49	0.90	0.51	1.01	0.85	0.48	0.96	0.81	0.46	0.91	0.74	0.42	0.83	0.68	0.38	0.77
1	4	9	1	15.2	34.2	44	0.84	0.47	1.06	0.80	0.45	1.01	0.76	0.43	0.96	0.68	0.38	0.86	0.63	0.35	0.80
1	4	10	1	15.2	38.0	40	0.79	0.44	1.11	0.75	0.42	1.06	0.71	0.40	1.00	0.64	0.36	0.90	0.58	0.33	0.82
1	5	10	1	19.0	38.0	47	0.73	0.52	1.03	0.69	0.49	0.97	0.66	0.46	0.93	0.60	0.42	0.84	0.55	0.39	0.77
1	6	12	1	22.8	45.5	46	0.62	0.52	1.04	0.58	0.49	0.98	0.56	0.47	0.94	0.50	0.42	0.84	0.46	0.39	0.78

NOTE.—Variations in the fineness of the sand and the compacting of the concrete may affect the quantities 10% in either direction.

*Use 50% columns for broken stone screened to uniform size.

†Use 45% columns for average conditions and for broken stone with dust screened out.

‡Use 40% columns for gravel or mixed stone and gravel.

§Use these columns for scientifically graded mixtures.

QUANTITIES OF MATERIALS FOR ONE CUBIC YARD OF RAMMED CONCRETE. BASED ON A BARREL OF 4 CUBIC FEET.

(See important foot-notes, also p. 225.)

Proportions by Parts: Cement	Proportions by Parts: Sand	Proportions by Parts: Stone	Proportions by Volumes: Packed Cement	Proportions by Volumes: Loose Sand	Proportions by Volumes: Loose Stone	Volume of mortar in terms of percentage of volume of stone	50%*: Cement	50%*: Sand	50%*: Stone	45%†: Cement	45%†: Sand	45%†: Stone	40%‡: Cement	40%‡: Sand	40%‡: Stone	30%§: Cement	30%§: Sand	30%§: Stone	20%§: Cement	20%§: Sand	20%§: Stone
			bbl.	cu. ft.	cu. ft.	%	bbl.	cu yd.	cu. yd.	bbl.	cu. yd	cu. yd.	bbl.	cu. yd.	cu. yd.	bbl.	cu. yd.	cu. yd.	bbl.	cu. yd.	cu. yd.
1		1	1		4	89	4.99		0.74	4.80		0.71	4.62		0.69	4.23		0.63	3.91		0.58
1		2	1		8	49	3.57		1.06	3.37		1.00	3.20		0.95	2.84		0.84	2.56		0.76
1		3	1		12	35				2.60		1.16	2.45		1.09	2.13		0.95	1.90		0.84
1		4	1		16	28										1.71		1.01	1.51		0.89
1		5	1		20	24										1.43		1.06	1.26		0.93
1		6	1		24	22										1.22		1.08	1.07		0.95
1		7	1		28	20													0.94		0.98
1		8	1		32	18													0.83		0.98
1		9	1		36	17													0.75		1.00
1		10	1		40	16													0.68		1.01
1		11	1		44	15													0.62		1.01
1		12	1		48	15													0.57		1.01
1	1	1½	1	4	6	96	3.08	0.46	0.68	2.97	0.44	0.66	2.87	0.42	0.64	2.69	0.40	0.60	2.53	0.38	0.56
1	1	2	1	4	8	73	2.74	0.41	0.81	2.63	0.39	0.78	2.52	0.37	0.75	2.33	0.34	0.69	2.17	0.32	0.64
1	1	2½	1	4	10	59	2.47	0.37	0.91	2.35	0.35	0.87	2.25	0.33	0.83	2.06	0.31	0.76	1.90	0.28	0.71
1	1	3	1	4	12	50	2.25	0.33	1.00	2.13	0.32	0.95	2.03	0.30	0.90	1.85	0.27	0.82	1.70	0.25	0.76
1	1½	2	1	6	8	92	2.39	0.53	0.71	2.30	0.51	0.68	2.22	0.49	0.66	2.07	0.46	0.61	1.94	0.43	0.58
1	1½	2½	1	6	10	74	2.18	0.48	0.81	2.09	0.46	0.77	2.01	0.45	0.74	1.86	0.41	0.69	1.73	0.38	0.64
1	1½	3	1	6	12	62	2.01	0.45	0.89	1.91	0.42	0.85	1.83	0.41	0.81	1.68	0.37	0.75	1.56	0.35	0.69
1	1½	3½	1	6	14	54	1.86	0.41	0.96	1.77	0.39	0.92	1.68	0.37	0.87	1.54	0.34	0.80	1.42	0.32	0.74
1	1½	4	1	6	16	48	1.73	0.38	1.03	1.64	0.36	0.97	1.56	0.35	0.92	1.42	0.32	0.84	1.30	0.29	0.77
1	1½	4½	1	6	18	43	1.62	0.36	1.08	1.53	0.34	1.02	1.45	0.32	0.97	1.31	0.29	0.87	1.20	0.27	0.80
1	1½	5	1	6	20	39	1.52	0.34	1.13	1.43	0.32	1.06	1.35	0.30	1.00	1.22	0.27	0.90	1.11	0.25	0.82
1	2	3	1	8	12	74	1.81	0.54	0.80	1.74	0.52	0.77	1.67	0.50	0.74	1.54	0.46	0.68	1.44	0.43	0.64
1	2	3½	1	8	14	64	1.69	0.50	0.88	1.61	0.48	0.83	1.54	0.46	0.80	1.42	0.42	0.74	1.31	0.39	0.68
1	2	4	1	8	16	56	1.58	0.47	0.94	1.51	0.45	0.89	1.44	0.43	0.85	1.32	0.39	0.78	1.21	0.36	0.72
1	2	4½	1	8	18	51	1.49	0.44	0.99	1.41	0.42	0.94	1.34	0.40	0.89	1.23	0.36	0.82	1.13	0.34	0.75
1	2	5	1	8	20	46	1.40	0.42	1.04	1.33	0.39	0.98	1.26	0.37	0.93	1.15	0.34	0.85	1.05	0.31	0.78
1	2	5½	1	8	22	42	1.33	0.39	1.08	1.26	0.37	1.03	1.19	0.35	0.97	1.08	0.32	0.88	0.98	0.29	0.80
1	2	6	1	8	24	39	1.26	0.37	1.12	1.19	0.35	1.06	1.13	0.34	1.00	1.02	0.30	0.91	0.93	0.28	0.83
1	2½	3	1	10	12	86	1.65	0.61	0.73	1.59	0.59	0.71	1.53	0.57	0.68	1.42	0.52	0.63	1.33	0.49	0.59
1	2½	3½	1	10	14	75	1.55	0.57	0.80	1.48	0.55	0.77	1.42	0.52	0.74	1.32	0.49	0.68	1.23	0.46	0.64
1	2½	4	1	10	16	66	1.46	0.54	0.87	1.39	0.51	0.82	1.33	0.49	0.79	1.23	0.46	0.73	1.14	0.42	0.68
1	2½	4½	1	10	18	59	1.38	0.51	0.92	1.31	0.48	0.87	1.25	0.46	0.83	1.15	0.43	0.77	1.06	0.39	0.71
1	2½	5	1	10	20	54	1.31	0.48	0.97	1.24	0.46	0.92	1.18	0.44	0.87	1.08	0.40	0.80	0.99	0.37	0.73
1	2½	5½	1	10	22	49	1.24	0.46	1.01	1.18	0.44	0.96	1.12	0.41	0.91	1.02	0.38	0.83	0.93	0.34	0.76
1	2½	6	1	10	24	45	1.18	0.44	1.05	1.12	0.41	1.00	1.06	0.39	0.94	0.96	0.36	0.85	0.88	0.33	0.78
1	2½	6½	1	10	26	42	1.13	0.42	1.09	1.07	0.40	1.03	1.01	0.37	0.97	0.92	0.34	0.89	0.84	0.31	0.81
1	2½	7	1	10	28	39	1.08	0.40	1.12	1.02	0.38	1.06	0.96	0.36	1.00	0.87	0.32	0.90	0.79	0.29	0.82
1	3	4	1	12	16	75	1.35	0.60	0.80	1.30	0.58	0.77	1.25	0.56	0.74	1.15	0.51	0.68	1.08	0.48	0.64
1	3	4½	1	12	18	67	1.28	0.57	0.85	1.23	0.55	0.82	1.18	0.52	0.79	1.08	0.48	0.72	1.01	0.45	0.67
1	3	5	1	12	20	60	1.22	0.54	0.90	1.16	0.52	0.86	1.11	0.49	0.82	1.02	0.45	0.76	0.94	0.42	0.70
1	3	5½	1	12	22	55	1.16	0.52	0.95	1.11	0.49	0.90	1.06	0.47	0.86	0.97	0.43	0.79	0.89	0.40	0.72
1	3	6	1	12	24	50	1.11	0.49	0.99	1.06	0.47	0.94	1.01	0.45	0.90	0.92	0.41	0.82	0.84	0.37	0.75
1	3	6½	1	12	26	48	1.06	0.47	1.02	1.01	0.45	0.97	0.96	0.43	0.92	0.87	0.39	0.84	0.80	0.36	0.77
1	3	7	1	12	28	44	1.02	0.45	1.06	0.97	0.43	1.01	0.92	0.41	0.95	0.83	0.37	0.86	0.76	0.34	0.79
1	3	7½	1	12	30	42	0.98	0.44	1.09	0.93	0.41	1.03	0.88	0.39	0.98	0.79	0.35	0.88	0.73	0.32	0.81
1	3	8	1	12	32	39	0.94	0.42	1.11	0.89	0.40	1.05	0.84	0.37	1.00	0.76	0.34	0.90	0.69	0.31	0.82
1	4	5	1	16	20	75	1.08	0.64	0.80	1.03	0.61	0.76	0.99	0.59	0.73	0.92	0.55	0.68	0.86	0.51	0.64
1	4	6	1	16	24	68	0.99	0.59	0.88	0.95	0.56	0.84	0.91	0.54	0.81	0.83	0.49	0.74	0.77	0.46	0.68
1	4	7	1	16	28	55	0.92	0.54	0.95	0.88	0.52	0.91	0.83	0.49	0.86	0.76	0.45	0.79	0.70	0.42	0.73
1	4	8	1	16	32	48	0.86	0.51	1.02	0.81	0.48	0.96	0.77	0.46	0.91	0.70	0.42	0.83	0.64	0.38	0.76
1	4	9	1	16	36	43	0.80	0.47	1.07	0.76	0.45	1.01	0.72	0.43	0.96	0.65	0.39	0.87	0.60	0.36	0.80
1	4	10	1	16	40	40	0.75	0.44	1.11	0.71	0.42	1.05	0.67	0.40	0.99	0.61	0.36	0.90	0.55	0.33	0.81
1	5	10	1	20	40	47	0.70	0.52	1.04	0.66	0.49	0.98	0.63	0.47	0.93	0.57	0.42	0.84	0.52	0.38	0.77
1	6	12	1	24	48	46	0.59	0.52	1.05	0.56	0.50	1.00	0.53	0.47	0.94	0.48	0.43	0.85	0.44	0.39	0.78

NOTE.—Variations in the fineness of the sand and the compacting of the concrete may affect the quantities by the 10% in either direction.

*Use 50% columns for broken stone screened to uniform size.

†Use 45% columns for average conditions and for broken stone with dust screened out.

‡Use 40% columns for gravel or mixed stone and gravel.

§Use these columns for scientifically graded mixtures.

VOLUME OF CONCRETE BASED ON A BARREL OF 3.5 CUBIC FEET.

(See important foot-notes, also p. 225.)

PROPORTIONS BY PARTS			PROPORTIONS BY VOLUME			Volume of mortar in terms of percentage of volume of stone	AVERAGE VOLUME OF RAMMED CONCRETE MADE FROM ONE BARREL CEMENT — Percentages of Voids in Broken Stone or Gravel				
Cement	Sand	Stone	Cement	Sand	Stone		50%*	45%†	40%‡	30%§	20%§
			bbl.	cu. ft.	cu. ft.	%	cu. ft.	cu. ft.	cu. ft	cu. ft.	cu. ft.
1		1	1		3.5	101	5.1	5.3	5.5	6.0	6.4
1		2	1		7.0	54	7.0	7.4	7.8	8.7	9.6
1		3	1		10.5	39		9.5	10.0	11.5	12.8
1		4	1		14.0	31				14.2	16.0
1		5	1		17.5	27				17.0	19.2
1		6	1		21.0	24				19.7	22.4
1		7	1		24.5	21					25.6
1		8	1		28.0	20					28.8
1		9	1		31.5	18					32.0
1		10	1		35.0	17					35.2
1		11	1		38.5	16					38.4
1		12	1		42.0	16					41.6
1	1	1½	1	3.5	5.2	104	8.0	8.3	8.6	9.1	9.7
1	1	2	1	3.5	7.0	78	8.9	9.3	9.7	10.5	11.2
1	1	2½	1	3.5	8.7	64	9.9	10.4	10.8	11.8	12.7
1	1	3	1	3.5	10.5	54	10.8	11.4	12.0	13.1	14.2
1	1½	2	1	5.2	7.0	95	10.2	10.6	11.0	11.7	12.5
1	1½	2½	1	5.2	8.7	78	11.2	11.6	12.1	13.0	14.0
1	1½	3	1	5.2	10.5	65	12.1	12.7	13.2	14.4	15.5
1	1½	3½	1	5.2	12.2	56	13.0	13.7	14.4	15.7	17.0
1	1½	4	1	5.2	14.0	50	14.0	14.8	15.5	17.0	18.5
1	1½	4½	1	5.2	15.7	45	14.9	15.8	16.6	18.3	20.0
1	1½	5	1	5.2	17.5	41	15.9	16.8	17.8	20.0	21.6
1	2	3	1	7.0	10.5	77	13.4	13.9	14.5	15.6	16.8
1	2	3½	1	7.0	12.2	67	14 3	15.0	15.6	17.0	18.3
1	2	4	1	7.0	14.0	59	15.3	16.0	16.8	18.3	19.8
1	2	4½	1	7.0	15.7	53	16.2	17.0	17.9	19.6	21.3
1	2	5	1	7.0	17.5	48	17.1	18.1	19.0	20.9	22.8
1	2	5½	1	7.0	19.2	44	18.1	19.1	20.2	22.2	24.3
1	2	6	1	7.0	21.0	41	19.0	20.2	21.3	23.6	25.8
1	2½	3	1	8.7	10.5	90	14.6	15.2	15.8	16.9	18.0
1	2½	3½	1	8.7	12.2	78	15.6	16.2	16.9	18.2	19.6
1	2½	4	1	8.7	14.0	68	16.5	17.3	18.0	19.6	21.1
1	2½	4½	1	8.7	15.7	61	17.5	18.3	19.2	20.9	22.6
1	2½	5	1	8.7	17.5	55	18.4	19.4	20.3	22.2	24.1
1	2½	5½	1	8.7	19.2	51	19.4	20.4	21.4	23.5	25.6
1	2½	6	1	8.7	21.0	47	20.3	21.4	22.6	24.8	27.1
1	2½	6½	1	8.7	22.7	44	21.2	22.5	23.7	26.2	28.6
1	2½	7	1	8.7	24.5	41	22.2	23.5	24.8	27.5	30.1
1	3	4	1	10.5	14.0	77	17.8	18.5	19.3	20.8	22.3
1	3	4½	1	10.5	15.7	69	18.7	19.6	20.4	22.1	23.8
1	3	5	1	10.5	17.5	62	19.7	20.6	21.6	23.4	25.3
1	3	5½	1	10.5	19.2	57	20.6	21.7	22.7	24.8	26.8
1	3	6	1	10.5	21.0	53	21.6	22.7	23.8	26.1	28.4
1	3	6½	1	10.5	22.7	49	22.5	23.7	25.0	27.4	29.9
1	3	7	1	10.5	24.5	46	23.5	24.8	26.1	28.7	31.4
1	3	7½	1	10.5	26.2	43	24.4	25.8	27.2	30.1	32.9
1	3	8	1	10.5	28.0	40	25.3	26.9	28.4	31.4	34.4
1	4	5	1	14.0	17.5	77	22.2	23.2	24.1	26.0	27.9
1	4	6	1	14.0	21.0	65	24.1	25.2	26.4	28.6	30.9
1	4	7	1	14.0	24.5	56	26.0	27.3	28.6	31.3	33.9
1	4	8	1	14.0	28.0	50	27.9	29.4	30.9	33.9	36.9
1	4	9	1	14.0	31.5	45	29.8	31.5	33.2	36.6	40.0
1	4	10	1	14.0	35.0	41	31.7	33.6	35.4	39.2	43.0
1	5	10	1	17.5	35.0	48	34.2	36.1	38.0	41.8	45.5
1	6	12	1	21.0	42.0	46	40.5	42.8	45.0	49.6	54.1

NOTE.—Variations in the fineness of the sand and the compacting of the concrete may affect the volumes by 10% in either direction.

*Use 50% column for broken stone screened to uniform size.

†Use 45% column for average conditions and for broken stone with dust screened out.

‡Use 40% colums for gravel or mixed stone and gravel.

§Use these colums for scientifically graded mixtures.

VOLUME OF CONCRETE BASED ON A BARREL OF 3.8 CUBIC FEET.

(See important foot-notes, also p. 225.)

Proportions by Parts: Cement	Sand	Stone	Proportions by Volume: Cement bbl	Sand cu. ft.	Stone cu. ft.	Volume of mortar in terms of percentage of volume of stone %	Average Volume of Rammed Concrete made from One Barrel Cement — Percentages of Voids in Broken Stone or Gravel: 50%* cu. ft.	45%† cu. ft.	40%‡ cu. ft.	30%§ cu. ft.	20%§ cu. ft.
1		1	1		3.8	94	5.3	5.5	5.7	6.2	6.7
1		2	1		7.6	51	7.4	7.8	8.2	9.2	10.2
1		3	1		11.4	36		10.0	10.6	12.2	13.6
1		4	1		15.2	29				15.2	17.1
1		5	1		19.0	25				18.2	20.6
1		6	1		22.8	22				21.1	24.0
1		7	1		26.6	20					27.5
1		8	1		30.4	19					31.0
1		9	1		34.2	18					34.4
1		10	1		38.0	17					37.9
1		11	1		41.8	16					41.4
1		12	1		45.5	15					44.8
1	1	1½	1	3.8	5.7	99	8.5	8.8	9.1	9.7	10.3
1	1	2	1	3.8	7.6	75	9.5	9.9	10.3	11.1	11.9
1	1	2½	1	3.8	9.5	61	10.5	10.0	11.5	12.6	13.6
1	1	3	1	3.8	11.4	51	11.5	12.2	12.8	14.0	15.2
1	1½	2	1	5.7	7.6	98	10.8	11.3	11.7	12.5	13.3
1	1½	2½	1	5.7	9.5	76	11.9	12.4	12.9	13.9	15.0
1	1½	3	1	5.7	11.4	64	12.9	13.5	14.1	15.4	16.6
1	1½	3½	1	5.7	13.3	55	13.9	14.6	15.4	16.8	18.2
1	1½	4	1	5.7	15.2	49	15.0	15.8	16.6	18.2	19.9
1	1½	4½	1	5.7	17.1	44	16.0	16.9	17.8	19.7	21.5
1	1½	5	1	5.7	19.0	40	17.0	18.0	19.1	21.1	23.2
1	2	3	1	7.6	11.4	75	14.3	14.9	15.5	16.7	18.0
1	2	3½	1	7.6	13.3	65	15.3	16.0	16.8	18.2	19.6
1	2	4	1	7.6	15.2	57	16.3	17.2	18.0	19.6	21.3
1	2	4½	1	7.6	17.1	51	17.4	18.3	19.2	21.0	22.9
1	2	5	1	7.6	19.0	47	18.4	19.4	20.4	22.5	24.5
1	2	5½	1	7.6	20.9	43	19.4	20.5	21.7	23.9	26.2
1	2	6	1	7.6	22.8	40	20.4	21.7	22.9	25.4	27.8
1	2½	3	1	9.5	11.4	87	15.7	16.3	16.9	18.1	19.3
1	2½	3½	1	9.5	13.3	75	16.7	17.4	18.1	19.6	21.0
1	2½	4	1	9.5	15.2	66	17.7	18.5	19.3	21.0	22.6
1	2½	4½	1	9.5	17.1	60	18.7	19.6	20.6	22.4	24.3
1	2½	5	1	9.5	19.0	54	19.8	20.8	21.8	23.9	25.9
1	2½	5½	1	9.5	20.9	49	20.8	21.9	23.0	25.8	27.6
1	2½	6	1	9.5	22.8	46	21.8	23.0	24.3	26.7	29.2
1	2½	6½	1	9.5	24.7	42	22.8	24.2	25.5	28.2	30.8
1	2½	7	1	9.5	26.6	40	23.9	25.3	26.7	29.6	32.5
1	3	4	1	11.4	15.2	76	19.1	19.9	20.7	22.4	24.0
1	3	4½	1	11.4	17.1	68	20.1	21.0	21.9	23.8	25.6
1	3	5	1	11.4	19.0	61	21.1	22.1	23.2	25.2	27.2
1	3	5½	1	11.4	20.9	56	22.1	23.3	24.4	26.7	28.9
1	3	6	1	11.4	22.8	52	23.2	24.4	25.6	28.1	30.6
1	3	6½	1	11.4	24.7	48	24.2	25.5	26.9	29.5	32.2
1	3	7	1	11.4	26.6	45	25.2	26.7	28.1	31.0	33.8
1	3	7½	1	11.4	28.5	42	26.2	27.8	29.3	32.4	35.5
1	3	8	1	11.4	30.4	40	27.3	28.9	30.6	33.8	37.1
1	4	5	1	15.2	19.0	76	23.9	24.9	25.9	28.0	30.0
1	4	6	1	15.2	22.8	64	25.9	27.2	28.4	30.8	33.3
1	4	7	1	15.2	26.6	55	28.0	29.4	30.8	33.7	36.6
1	4	8	1	15.2	30.4	49	30.0	31.7	33.3	36.6	39.9
1	4	9	1	15.2	34.2	44	32.1	33.9	35.8	39.4	43.1
1	4	10	1	15.2	38.0	40	34.1	36.2	38.2	42.3	46.4
1	5	10	1	19.0	38.0	47	36.9	38.9	41.0	45.1	49.2
1	6	12	1	22.8	45.5	46	43.7	46.2	48.6	53.6	58.5

NOTE.—Variations in the fineness of the sand and the compacting of the concrete may affect the volumes by 10% in either direction.

*Use 50% column for broken stone screened to iniform size.

†**Use 45% column for average conditions** and for broken stone with dust screened out.

‡Use 40% column for gravel or mixed stone and gravel.

§Use these columna for scientifically graded mixtures.

VOLUME OF CONCRETE BASED ON A BARREL OF 4 CUBIC FEET.

(See important foot-notes, also p. 225.)

PROPORTIONS BY PARTS			PROPORTIONS BY VOLUME			Volume of mortar in terms of percentage of volume of stone	AVERAGE VOLUME OF RAMMED CONCRETE MADE FROM ONE BARREL CEMENT — Percentages of Voids in Broken Stone or Gravel				
Cement	Sand	Stone	Cement	Sand	Stone		50%*	45%†	40%‡	30%§	20%§
			bbl.	cu. ft.	cu. ft.	%	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
1		1	1		4	89	5.4	5.6	5.8	6.4	6.9
1		2	1		8	49	7.6	8.0	8.4	9.5	10.5
1		3	1		12	35		10.4	11.0	12.7	14.2
1		4	1		16	28				15.8	17.8
1		5	1		20	24				18.9	21.5
1		6	1		24	22				22.1	25.1
1		7	1		28	20					28.8
1		8	1		32	18					32.4
1		9	1		36	17					36.1
1		10	1		40	16					39.7
1		11	1		44	15					43.4
1		12	1		48	15					47.0
1	1	1½	1	4	6	96	8.8	9.1	9.4	10.0	10.7
1	1	2	1	4	8	73	9.8	10.3	10.7	11.6	12.4
1	1	2½	1	4	10	59	10.9	11.5	12.0	13.1	14.2
1	1	3	1	4	12	50	12.0	12.7	13.3	14.6	15.9
1	1½	2	1	6	8	92	11.3	11.7	12.2	13.0	13.9
1	1½	2½	1	6	10	74	12.4	12.9	13.5	14.5	15.6
1	1½	3	1	6	12	69	13.5	14.1	14.8	16.0	17.3
1	1½	3½	1	6	14	54	14.5	15.3	16.0	17.6	19.1
1	1½	4	1	6	16	48	15.6	16.5	17.3	19.1	20.8
1	1½	4½	1	6	18	43	16.7	17.7	18.6	20.6	22.5
1	1½	5	1	6	20	39	17.8	18.9	19.9	22.1	24.3
1	2	3	1	8	12	74	14.9	15.6	16.2	17.5	18.8
1	2	3½	1	8	14	64	16.0	16.7	17.5	19.0	20.5
1	2	4	1	8	16	56	17.1	17.9	18.8	20.5	22.3
1	2	4½	1	8	18	51	18.1	19.1	20.1	22.0	23.9
1	2	5	1	8	20	46	19.2	20.3	21.4	23.5	25.7
1	2	5½	1	8	22	42	20.3	21.5	22.7	25.1	27.4
1	2	6	1	8	24	39	21.4	22.7	24.0	26.6	29.2
1	2½	3	1	10	12	86	16.3	17.0	17.6	18.9	20.2
1	2½	3½	1	10	14	75	17.4	18.2	18.9	20.5	22.0
1	2½	4	1	10	16	66	18.5	19.4	20.2	21.9	23.7
1	2½	4½	1	10	18	60	19.6	20.6	21.5	23.5	25.4
1	2½	5	1	10	20	54	20.7	21.8	22.8	25.0	27.2
1	2½	5½	1	10	22	49	21.8	22.9	24.1	26.5	28.9
1	2½	6	1	10	24	45	22.8	24.1	25.4	28.0	30.6
1	2½	6½	1	10	26	42	23.9	25.3	26.7	29.5	32.3
1	2½	7	1	10	28	39	25.0	26.5	28.0	31.0	34.0
1	3	4	1	12	16	75	20.0	20.8	21.7	23.4	25.1
1	3	4½	1	12	18	67	21.0	22.0	23.0	24.9	26.8
1	3	5	1	12	20	60	22.1	23.2	24.3	26.4	28.6
1	3	5½	1	12	22	55	23.2	24.4	25.6	28.0	30.3
1	3	6	1	12	24	50	24.3	25.6	26.9	29.5	32.1
1	3	6½	1	12	26	48	25.4	26.8	28.2	31.0	33.8
1	3	7	1	12	28	44	26.4	27.9	29.4	32.5	35.5
1	3	7½	1	12	30	42	27.5	29.1	30.8	34.0	37.2
1	3	8	1	12	32	39	28.6	30.3	32.0	35.5	39.0
1	4	5	1	16	20	75	25.0	26.1	27.2	29.3	31.5
1	4	6	1	16	24	63	27.2	28.5	29.8	32.4	35.0
1	4	7	1	16	28	55	29.3	30.8	32.4	35.4	38.4
1	4	8	1	16	32	48	31.5	33.2	34.9	38.4	41.9
1	4	9	1	16	36	43	33.6	35.6	37.5	41.4	45.3
1	4	10	1	16	40	40	35.8	38.0	40.1	44.4	48.8
1	5	10	1	20	40	47	38.7	40.9	43.0	47.3	51.7
1	6	12	1	24	48	46	45.9	48.5	51.1	56.3	61.4

NOTE.—Variations in the fineness of the sand and the compacting of the concrete may affect the volumes by 10% in either direction.

*Use 50% column for broken stone screened to uniform size.

†Use 45% column for average conditions and for broken stone with dust screened out.

‡Use 40% column for gravel or mixed stone and gravel.

§Use these columns for scientifically graded mixtures.

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SAFE LOADING AND REINFORCEMENT FOR STONE CONCRETE BEAMS ONE INCH IN WIDTH. 1:2½:5 CONCRETE. MILD STEEL.

From formula $w = \frac{(h-e)^2 Kb}{1.5\,l^2} = 58\left(\frac{d}{l}\right)^2$ Based on 0.69% steel and $K = 87$. (*See p.* 312, *and Item* (15), *p.* 302.)
$E = 3\,000\,000$ $r = 10$ $C = 625$ $S = 14\,000$

Depth of Beam.	Total Safe Load (w) per Linear Foot for Beam One Inch Wide, including Weight of Beam. *For safe live load deduct weight of beam in column (22).* (See important foot-notes.) Span in Feet (l).																		Weight of Beam one inch wide per linear foot.	Depth to Steel.	Depth below Steel.	Steel Area in a Beam One Inch Wide.	Safe Moment of Resistance. (*See p.* 298.
(h) in.	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30	35	lb.	(d) in.	(e) in.	sq. in.	(MR) in.-lb.
																				(22)	(23)	(24)	(25)	(26)
5	37	26	19	14	12	9	8													5.4	4.0	1.0	0.028	1390
6	58	40	30	23	18	14	12	10	9											6.4	5.0	1.0	0.034	2180
7	84	58	43	33	26	21	17	14	12	11										7.5	6.0	1.0	0.041	3130
8	114	79	58	44	35	28	24	20	17	14	13									8.6	7.0	1.0	0.048	4260
9	139	97	71	54	43	35	29	24	21	18	16									9.6	7.75	1.25	0.054	5220
10	178	123	91	69	55	44	37	31	26	23	20	17								10.7	8.75	1.25	0.060	6660
11	221	153	113	86	68	55	46	38	33	28	24	22	19							11.8	9.75	1.25	0.067	8270
12	268	186	137	105	83	67	55	47	40	34	30	26	23	21						12.8	10.75	1.25	0.074	10060
13	307	213	157	120	95	77	63	53	45	39	34	30	27	24	21					13.9	11.50	1.5	0.079	11500
14	363	252	185	142	112	91	75	63	54	46	40	35	31	28	25	23				15.0	12.5	1.5	0.086	13590
15	423	294	216	165	131	106	87	73	63	54	47	41	37	33	29	26				16.0	13.5	1.5	0.093	15860
16	488	339	249	191	151	122	101	85	72	62	54	48	42	38	34	30				17.1	14.5	1.5	0.100	18290
17	557	387	284	218	172	139	115	97	83	71	62	54	48	43	39	35				18.1	15.5	1.5	0.107	20900
18	632	439	322	247	195	158	130	110	93	81	70	62	55	49	44	40				19.2	16.5	1.5	0.114	23680
19	670	466	342	262	207	168	139	116	99	86	74	66	58	52	46	42				20.3	17.0	2.0	0.117	25140
20		522	384	294	232	188	155	131	111	96	83	73	65	58	52	47	30			21.4	18.0	2.0	0.124	28190
22		644	474	363	286	232	192	161	137	118	103	91	80	72	64	58	37			23.6	20.0	2.0	0.138	34800
24			573	439	346	281	232	195	166	143	125	110	97	87	78	70	45			25.7	22.0	2.0	0.152	42100
26			682	522	412	334	276	232	198	170	148	130	116	103	93	83	53			27.9	24.0	2.0	0.166	50100
28				613	484	392	324	272	232	200	174	153	136	121	109	98	63	44		30.0	26.0	2.0	0.179	58800
30					561	455	376	316	269	232	202	178	157	140	126	114	73	50		32.1	28.0	2.0	0.193	68200
36						651	538	452	385	332	289	254	225	201	180	163	104	72	53	38.5	33.5	2.5	0.231	97640
42								628	535	462	402	354	313	279	251	226	145	101	74	44.9	39.5	2.5	0.273	135720
48									711	613	534	469	416	371	333	300	192	133	98	51.4	45.5	2.5	0.314	180100

RULES.
1. For safe load of any width of beam multiply by width in inches.
2. For area of cross-section of steel for any width of beam multiply column (25) by width in inches.
3. Total loads for other spans (l) and same depth of steel are inversely proportional to the squares of the spans.
4. Total loads for other depths of steel (d) and same span are proportional to the squares of the depths of steel.
5. For 1:3:6 concrete, or well-graded 1:3½:7 concrete, deduct 20% from safe loads and decrease steel areas, column (25), by 20%. See Item (16) or (26), p. 302.)—*Taylor & Thompson.*

Tables of
Weights, Areas and Sizes
of
Triangular and Square Mesh
Reinforcements

TRIANGULAR REINFORCEMENT 4-INCH MESH, WITH 14 GAUGE CROSS WIRES.
SIZES OF WIRES, AREAS AND TENSIL STRENGTH PER SQUARE FOOT, AND PER FOOT WIDTH.

WEIGHTS PER 100 SQUARE FEET. STR.—MINIMUM ULT. STRENGTH.

Size of Wire Longitudinals		One Wire each Longitudinal						2 Wires each Longitudinal						3 Wires each Longitudinal					
		Longitudinal Members	Cross Wires No. 14 Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires No. 14 Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires No 14 Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.
¼ In.	Area	.1472	.0251	.1723	.1622														
	Str.	9420	1605	11025	10380	1	59.9												
No. 4............	Area	.1192	.0251	.1443	.1342			.2384	.0251	.2635	.2534			.3576	.0251	.3827	.3726		
	Str.	7628	1605	9233	8588	2	50.7	15257	1605	16862	16217	9	88.9	22886	1605	24491	23846	16	129.4
No. 5............	Area	.1009	.0251	.1260	.1159			.2018	.0251	.2269	.2168			.3027	.0251	.3278	.3177		
	Str.	6457	1605	8062	7417	3	44.2	12915	1605	14520	13875	10	77.8	19372	1605	20977	20332	17	112.0
No. 6............	Area	.0868	.0251	.1119	.1018			.1737	.0251	.1988	.1887			.2605	.0251	.2856	.2755		
	Str.	5555	1605	7160	6515	4	39.8	11116	1605	12721	12076	11	68.0	16672	1605	18277	17632	18	96.5
No. 8............	Area	.0618	.0251	.0869	.0768			.1236	.0251	.1487	.1386			.1854	.0251	.2105	.2004		
	Str.	3955	1605	5560	4915	5	31.5	7910	1605	9515	8870	12	52.0	11865	1605	13470	12825	19	72.0
No. 10............	Area	.0429	.0251	.0680	.0579			.0858	.0251	.1109	1008			.1287	.0251	.1538	.1437		
	Str.	2745	1605	4350	3705	6	25.0	5491	1605	7096	6451	13	39.4	8236	1605	9841	9196	20	53.7
No. 12............	Area	.0259	.0251	.0510	.0409			.0519	.0251	.0770	.0669			.0778	.0251	.1029	.0928		
	Str.	1657	1605	3262	2617	7	19.5	3321	1605	4926	4281	14	28.3	4979	1605	6582	5939	21	37 2
No. 12½..........	Area	.0228	.0251	.0479	.0378			.0457	.0251	.0708	.0607			.0685	.0251	.0936	.0835		
	Str.	1459	1605	3064	2419	8	18.5	2924	1605	4529	3884	15	27.53	4384	1605	5989	5344	22	38.0

Special sizes, with larger areas, on application.

TRIANGULAR REINFORCEMENT 2-INCH MESH, WITH 14 GAUGE CROSS WIRES.
SIZES OF WIRE, AREAS AND TENSIL STRENGTH PER SQUARE FOOT, AND PER FOOT WIDTH.
WEIGHTS PER 100 SQUARE FEET. STR.—MINIMUM ULT. STRENGTH.

Size of Wire Longitudinals		One Wire each Longitudinal						2 Wires each Longitudinal						3 Wires each Longitudinal					
		Longitudinal Members	Cross Wires No. 14 Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires No. 14 Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires No. 14 Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.
¼ In.	Area	.1472	.0502	.1974	.1622														
	Str.	9420	3211	12631	10380	1A	63.9												
No. 4	Area	.1192	.0502	.1694	.1342			.2384	.0502	.2886	.2534			.3576	.0502	.4078	.3726		
	Str.	7628	3211	10839	8588	2A	54.8	15257	3211	18468	13217	9A	101.3	22886	3211	26097	23846	16A	140.8
No. 5	Area	.1009	.0502	.1511	.1159			.2018	.0502	.2520	.2168			.3027	.0502	.3529	.3177		
	Str.	6457	3211	9668	7417	3A	48.7	12915	3211	16126	13875	10A	89.0	19372	3211	22583	20392	17A	122.3
No. 6	Area	.0868	.0502	.1370	.1018			.1737	.0502	.2239	.1887			.2605	.0502	.3107	.2755		
	Str.	5555	3211	8766	6515	4A	43.9	11116	3211	14327	12076	11A	79.4	16672	3211	19883	17632	18A	108.2
No. 8	Area	.0618	.0502	.1120	.0768			.1236	.0502	.1738	.1386			.1854	.0201	.2356	.2004		
	Str.	3955	3211	7166	4915	5A	35.6	7910	3211	11121	8870	12A	62.6	11865	3211	15076	12825	19A	82.1
No. 10	Area	.0429	.0502	.0931	.0579			.0858	.0502	.1360	.1008			.1287	.0502	.1789	.1437		
	Str.	2745	3211	5956	3705	6A	29.6	5491	3211	8702	6451	13A	49.8	8236	3211	11447	9196	20A	64.2
No. 12	Area	.0259	.0502	.0761	.0409			.0519	.0502	.1021	.0669			.0778	.0502	.1280	.0928		
	Str.	1657	3211	4868	2617	7A	23.5	3321	3211	6532	4281	14A	38.3	4979	3211	8190	5939	21A	47.1
No. 12½	Area	.0228	.0502	.0730	.0378			.0457	.0502	.0959	.0607			.0685	.0502	.1187	.0835		
	Str	1459	3211	4670	2419	8A	22.4	2924	3221	6135	3884	15A	35.9	4384	3211	7595	5344	22A	43.4

Special sizes, with larger areas, on application.

TRIANGULAR REINFORCEMENT 4-INCH MESH, WITH 12 ½ GAUGE CROSS WIRES.
SIZES OF WIRE, AREAS AND TENSIL STRENGTH PER SQUARE FOOT, AND PER FOOT WIDTH.

WEIGHTS PER 100 SQUARE FEET. STR.—MINIMUM ULT. STRENGTH.

Size of Wire Longitudinals		One Wire each Longitudinal						2 Wires each Longitudinal						3 Wires each Longitudinal					
		Longitudinal Members	Cross Wires 12½ Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires 12½ Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires 12½ Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.
¼ In	Area	.1472	.0381	.1853	.1701														
	Str.	9420	2440	11860	10886	23	65.8												
No. 4............	Area	.1192	.0381	.1573	.1421			.2384	.0381	.2765	.2612			.3576	.0381	.3957	.3804		
	Str.	7628	2440	10068	9094	24	56.7	15257	2440	17697	16716	31	96.7	22886	2440	25324	24345	38	135.8
No. 5............	Area	.1009	.0381	.1390	.1237			.2018	.0381	2399	.2246			.3027	.0381	.3408	.3255		
	Str.	6457	2440	8897	7916	25	50.7	12915	2440	15355	14374	32	84.5	19372	2440	21812	20832	39	117.5
No. 6............	Area	.0868	.0381	.1249	.1096			.1737	.0381	.2118	.1965			.2605	.0381	.2986	.2833		
	Str.	5555	2440	7995	7014	26	45.8	11116	2440	13556	12576	33	75.0	16672	2440	19112	18131	40	103.4
No. 8............	Area	.0618	.0381	.0999	.0846			.1236	.0381	.1617	.1464			.1854	.0381	.2235	.2082		
	Str.	3955	2440	6395	5414	27	37.6	7910	2440	10350	9369	34	58.5	11865	2440	14305	13324	41	78.7
No. 10............	Area	.0429	.0381	.0810	.0657			.0858	.0381	.1239	.1086			.1287	.0381	.1668	.1515		
	Str.	2745	2440	5185	4204	28	31.3	5491	2440	7931	6950	35	45.9	8236	2440	10676	9696	42	60.1
No. 12......	Area	.0259	.0381	.0640	.0487			.0519	0381	.0900	.0747			.0778	.0381	.1159	.1006		
	Str.	1657	2440	4097	3116	29	25.6	3321	2440	5761	4780	36	34.7	4979	2440	7419	6438	43	43.4
No. 12½............	Area	.0228	.0381	.0609	.0456			.0457	.0381	.0838	.0685			.0685	.0381	.1066	.0913		
	Str.	1459	2440	3899	2918	30	24.4	2924	2440	5364	4384	37	32.4	4384	2440	6824	5843	44	40.0

Special sizes, with larger areas, on application.

TRIANGULAR REINFORCEMENT 2-INCH MESH, WITH 12½ GAUGE CROSS WIRES.
SIZES OF WIRE, AREAS AND TENSIL STRENGTH PER SQUARE FOOT, AND PER FOOT WIDTH.
WEIGHTS PER 100 SQUARE FEET. **STR.— MINIMUM ULT. STRENGTH.**

Size of Wire Longitudinals		One Wire each Longitudinal						2 Wires each Longitudinal						3 Wires each Longitudinal					
		Longitudinal Members	Cross Wires 12½ Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires 12½ Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq. ft.	Longitudinal Members	Cross Wires 12½ Gauge	Total per square foot	Cross section per ft. width	Style Numbers	Weight per 100 sq ft.
¼ In	Area	.1472	.0762	.2234	.1701														
	Str.	9420	4877	14297	10886	23A	82.1												
No. 4...........	Area	.1192	.0762	.1954	.1421			.2384	.0762	.3148	.2612			.3576	.0762	.4338	.3804		
	Str.	7628	4877	12505	9094	24A	72.7	15257	4877	20134	16716	31A	115.8	22886	4877	27763	24345	38A	154.9
No. 5............	Area	.1009	.0762	.1771	.1237			.2018	.0762	.2780	.2246			.3027	.0762	.3789	3255		
	Str.	6457	4877	11334	7916	25A	66.4	12915	4877	17792	14374	32A	102.1	19372	4877	24249	20832	39A	136.0
No. 6............	Area	.0868	.0762	.1630	.1096			.1737	.0762	.2499	.1965			.2605	.0762	.3369	.2833		
	Str.	5555	4877	10432	7014	26A	61.3	11116	4877	15993	12576	33A	92.2	16672	4877	21549	18131	40A	121.6
No. 8............	Area	.0618	.0762	.1380	.0846			.1236	.0762	.1998	.1464			.1854	.0762	.2616	.2082		
	Str.	3955	4877	8832	5414	27A	52.6	7910	4877	12787	9369	34A	75.0	11865	4877	16742	13324	41A	96.0
No. 10............	Area	.0429	.0762	.1191	.0657			.0858	.0762	.1620	.1086			.1287	.0762	.2049	.1515		
	Str.	2745	4877	7622	4204	28A	46.0	5491	4877	10368	6950	35A	61.8	8236	4877	13113	9696	42A	77.2
No. 12............	Area	.0259	.0762	.1021	.0487			.0519	.0762	.1281	.0747			.0778	.0762	.1540	.1006		
	Str.	1657	4877	6534	3116	29A	39.8	3321	4877	8198	4780	36A	49.8	4979	4877	9856	6438	43A	59.1
No. 12½..........	Area	.0228	.0762	.0990	.0456			.0457	.0762	.1219	.0685			.0685	.0762	.1447	.0913		
	Str.	1459	4877	6336	2918	30A	38.6	2924	4877	7801	4384	37A	47.4	4384	4877	9261	5843	44A	55.5

Special sizes, with larger areas, on application.

SQUARE MESH WIRE REINFORCEMENT. CROSS WIRES 6-INCH C-C.—12 GAUGE.

Weight per 100 square foot of fabric. See columns W.

Total area of steel in tension members, per foot width of fabric.

See columns A.

One Longitudinal Wire in each strand	Two inch Spacing				Four inch Spacing			
	Style No.	W. lbs.	A sq. in.	Min. Ult. strength per foot width	Style No.	W lbs.	A sq. in.	Min. Ult. strength per foot width
¼ In.	1 B	115.2	.295	18880	9 B	60.6	.147	9408
4	2 B	96.3	.239	15296	10 B	51.1	.120	7680
5	3 B	82.8	.202	12928	11 B	44.3	.101	6464
6	4 B	73.2	.174	11136	12 B	39.6	.087	5568
8	5 B	56.0	.124	7986	13 B	30.6	.062	3968
10	6 B	41.7	.086	5504	14 B	23.8	.043	2752
12	7 B	29.5	.052	3326	15 B	17.7	.026	1664

Special sizes, with larger areas, on application.

SQUARE MESH WIRE REINFORCEMENT. CROSS WIRES 12-INCH C-C.—12 GAUGE.

Weight per square foot of fabric. See columns W.

Total area of steel in tension members per foot width of fabric.

See columns A.

One Longitudinal Wire in each strand	Two inch Spacing				Four inch Spacing			
	Style No.	W lbs.	A sq. in.	Min. Ult. strength per foot width	Style No.	W lbs.	A sq. in.	Min. Ult. strength per foot width
¼ In.	23 B	107.4	.295	18880	31 B	55.2	.147	9408
4	24 B	88.5	.239	15296	32 B	45.8	.120	7680
5	25 B	75.7	.202	12928	33 B	39.3	.101	6464
6	26 B	66.1	.174	11136	34 B	34.5	.087	5568
8	27 B	49.0	.124	7936	35 B	25.8	.062	3968
10	28 B	35.5	.086	5504	36 B	19.2	.043	2752
12	29 B	23.6	.052	3326	37 B	13.3	.026	1664

Special sizes, with larger areas, on application.

Tables of Diagrams
of
Safe Bending Moments,
Weights and Thickness of Slabs,
Areas of Steel, Etc.

TABLE No. I.

SAFE BENDING MOMENTS, IN FOOT POUNDS PER FOOT WIDTH.

MIXTURE 1:2½:5.

Area of Cross Section of Steel Fabric in Square Inches per Foot of Width.

Total thickness of slab in inches	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85
2.5	103	203	298	390	479												
3.0	133	263	388	510	629	743											
3.5	163	323	478	630	779	923	1064										
4.0	193	383	568	750	929	1103	1274	1442									
4.5	223	443	658	870	1079	1283	1484	1682	1875								
5.0	253	503	748	990	1229	1463	1694	1922	2145	2365							
5.5	283	563	838	1110	1379	1643	1904	2162	2415	2665	2911						
6.0	313	623	928	1230	1529	1823	2114	2402	2685	2965	3241	3513					
6.5	343	683	1018	1350	1679	2003	2324	2642	2955	3265	3571	3873	4172				
7.0	373	743	1108	1470	1829	2183	2534	2882	3225	3565	3901	4233	4562	4887	5209		
7.5	403	803	1198	1590	1979	2363	2744	3122	3495	3865	4231	4593	4952	5307	5659	6006	6350
8.0	433	863	1288	1710	2129	2543	2954	3362	3765	4165	4561	4953	5342	5727	6109	6486	6860
8.5	463	923	1378	1830	2279	2723	3165	3602	4035	4465	4891	5313	5732	6147	6559	6966	7370
9.0	493	983	1468	1950	2429	2903	3374	3842	4305	4765	5221	5763	6122	6567	7009	7446	7880
9.5	523	1043	1558	2070	2579	3083	3584	4082	4575	5065	5551	6033	6512	6987	7459	7926	8390
10.0	553	1103	1648	2190	2729	3263	3794	4322	4845	5365	5881	6393	6902	7407	7909	8406	8900
10.5	583	1163	1738	2310	2879	3443	4004	4562	5115	5665	6211	6753	7292	7827	8359	8886	9410
11.0	613	1223	1828	2430	3029	3623	4214	4802	5385	5965	6541	7113	7682	8247	8809	9366	9920
11.5	643	1283	1918	2550	3179	3803	4424	5042	5655	6265	6871	7473	8072	8667	9259	9846	10430
12.0	673	1343	3008	2670	3329	3983	4634	5282	5925	6565	7201	7833	8462	9087	9709	10326	10940

Table No. 1 is based on the following formula:

In which $R = (.9 - P/15) \times A \times D \times 16000$.
R=Moment of resistance in foot pounds.
P=Ratio, per cent, of area of steel to area of concrete above the center of the reinforcement.
A=Area of steel in one foot of width—square inches.
D=Distance from top of slab to center of reinforcement in feet.

It is assumed that the center of the reinforcement is placed ¾ inch above bottom of slab.

The bending moment, which must not be greater than the moment of resistance, may be obtained by the following formula:

Moment$=\frac{1}{10}$ x (total load per sq. ft.) x (span in feet)^2.

The total load=the superficial or live load plus the weight of the slab, which may be assumed as 12 x the thickness of the slab.

The span may be taken as the clear distance between flanges of the supporting beams or girders.

Example of the application of the tables: To find the proper reinforcement for a slab having a clear span of 8 ft. to carry a superficial load of 250 lbs. per sq. ft.

Assuming a depth of 5 in. the weight of slab=5 x 12=	60
Live load=	250
Total load=	310

Moment$=\frac{1}{10}$ x 310 x 8^2=1984. (For slabs supported at each end only.)

For panels supported on all four sides, formula $\frac{1}{20}$ x LxSp^2=bending moment, should be used.

TABLE No. 2.

RECOMMENDED MINIMUM DEPTH OF SLABS IN INCHES.

SPAN IN FEET. MIXTURE 1:2½: 5.

Live load in lbs. per sq ft.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
50	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.5	3.5	4.0	4.0	5.0	5.0	5.5	5.5	6.0	6.5	7.0	7.5	8.0	8.0	8.5	9.0
100	2.5	2.5	2.5	2.5	3.0	3.0	3.5	4.0	4.5	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	10.5
150	2.5	2.5	2.5	3.0	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
200	2.5	2.5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.5	11.0	11.5	12.0		
250	2.5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.5	10.0	10.5	11.0	12.0				
300	2.5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.5	7.0	7.5	8.0	8.5	9.5	10.0	10.5	11.5	12.0					
350	2.5	2.5	3.0	3.5	4.5	5.0	5.5	6.0	6.5	7.5	8.0	8.5	9.0	10.0	10.5	11.5	12.0						
400	2.5	2.5	3.5	4.0	4.5	5.0	5.5	6.5	7.0	7.5	8.5	9.0	9.5	10.5	11.0	12.0							
450	2.5	2.5	3.5	4.0	4.5	5.5	6.0	6.5	7.5	8.0	8.5	9.5	10.0	11.0	11.5								
500	2.5	3.0	3.5	4.0	5.0	5.5	6.0	7.0	7.5	8.5	9.0	10.0	10.5	11.5	12.0								
550	2.5	3.0	3.5	4.5	5.0	6.0	6.5	7.0	8.0	8.5	9.5	10.0	11.0	12.0									
600	2.5	3.0	4.0	4.5	5.5	6.0	6.5	7.5	8.0	9.0	10.0	10.5	11.5	12.0									
650	2.5	3.0	4.0	4.5	5.5	6.0	7.0	7.5	8.5	9.5	10.0	11.0	12.0										
700	2.5	3.0	4.0	5.0	5.5	6.5	7.0	8.0	8.5	9.5	11.0	11.5	12.0										
750	2.5	3.0	4.0	5.0	5.5	6.5	7.5	8.0	9.5	10.0	11.0	11.5											
800	2.5	3.0	4.0	5.0	6.0	6.5	7.5	8.5	9.5	10.0	11.5	12.0											
850	2.5	3.5	4.5	5.0	6.0	7.0	7.5	8.5	9.5	10.5	11.5												
900	2.5	3.5	4.5	5.5	6.0	7.0	8.0	9.0	9.5	10.5	11.5												
950	2.5	3.5	4.5	5.5	6.0	7.0	8.0	9.0	10.0	11.0	12.0												
1000	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.0	10.0	11.0	12.0												

In the slabs given in table No. 2, provision is made for carrying their own dead weight, but all extra weights, such as filling and flooring on the top surface, or plastering below, should be considered as part of the live load given in the first column.

The depths given are the total thickness of the slab, assuming the center of the reinforcement to be ¾ inch above bottom. More covering than this may be used by increasing the depth, the extra weight of this concrete being added to the live load.

This table, which is based upon one per cent of steel, is not necessarily to be strictly followed. It is always allowable to use depths greater than those here specified, thereby decreasing the amount of reinforcement and increasing the amount of concrete. It is also possible to use somewhat less depths, but in this case table No. 1 will not apply and it necessary to use less than 16,000 pounds per square inch in the steel or the concrete will be overstrained. For depths greater than 12 inches, it is more economical to use reinforced concrete beams with thinner slabs between.

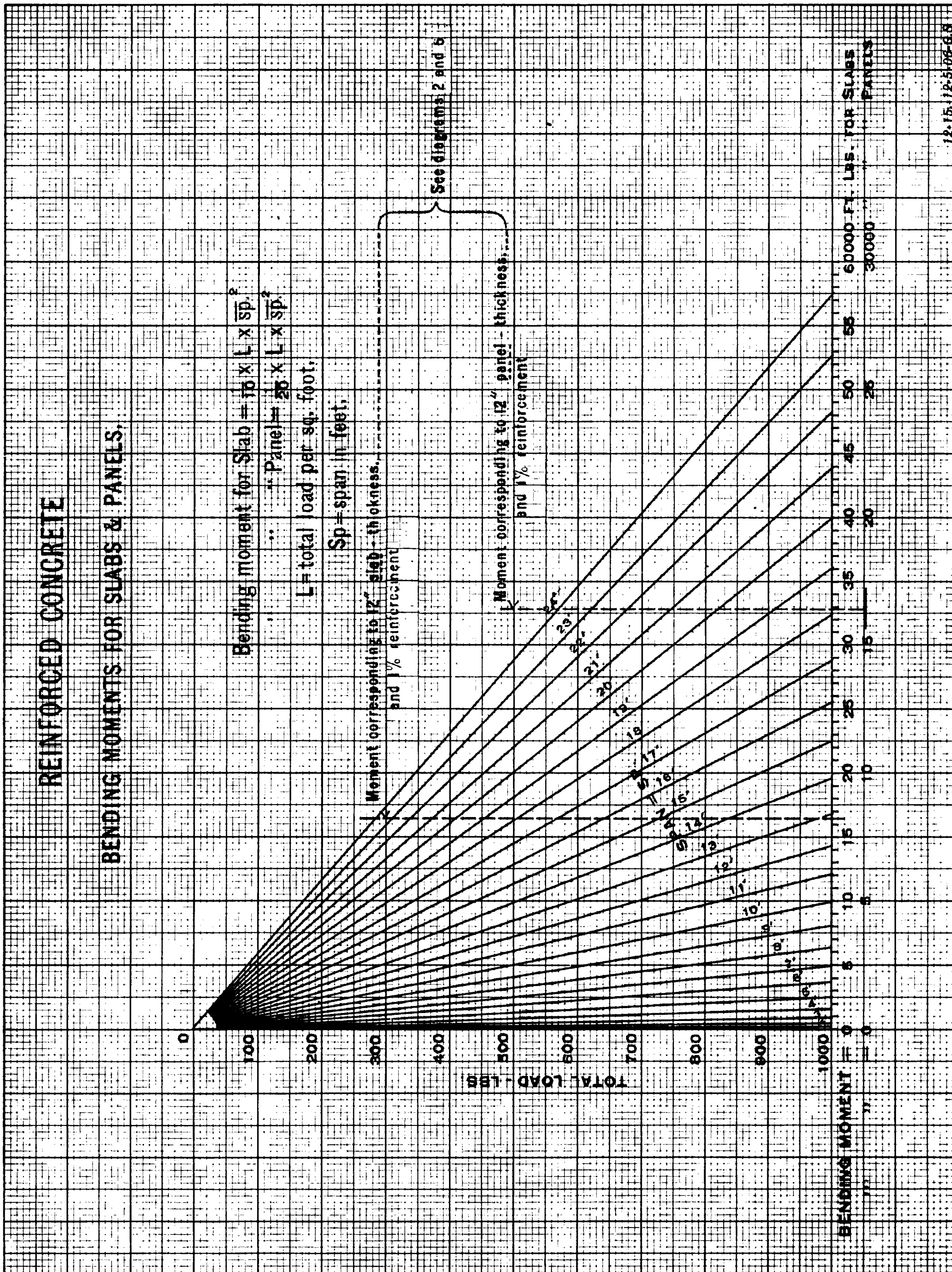
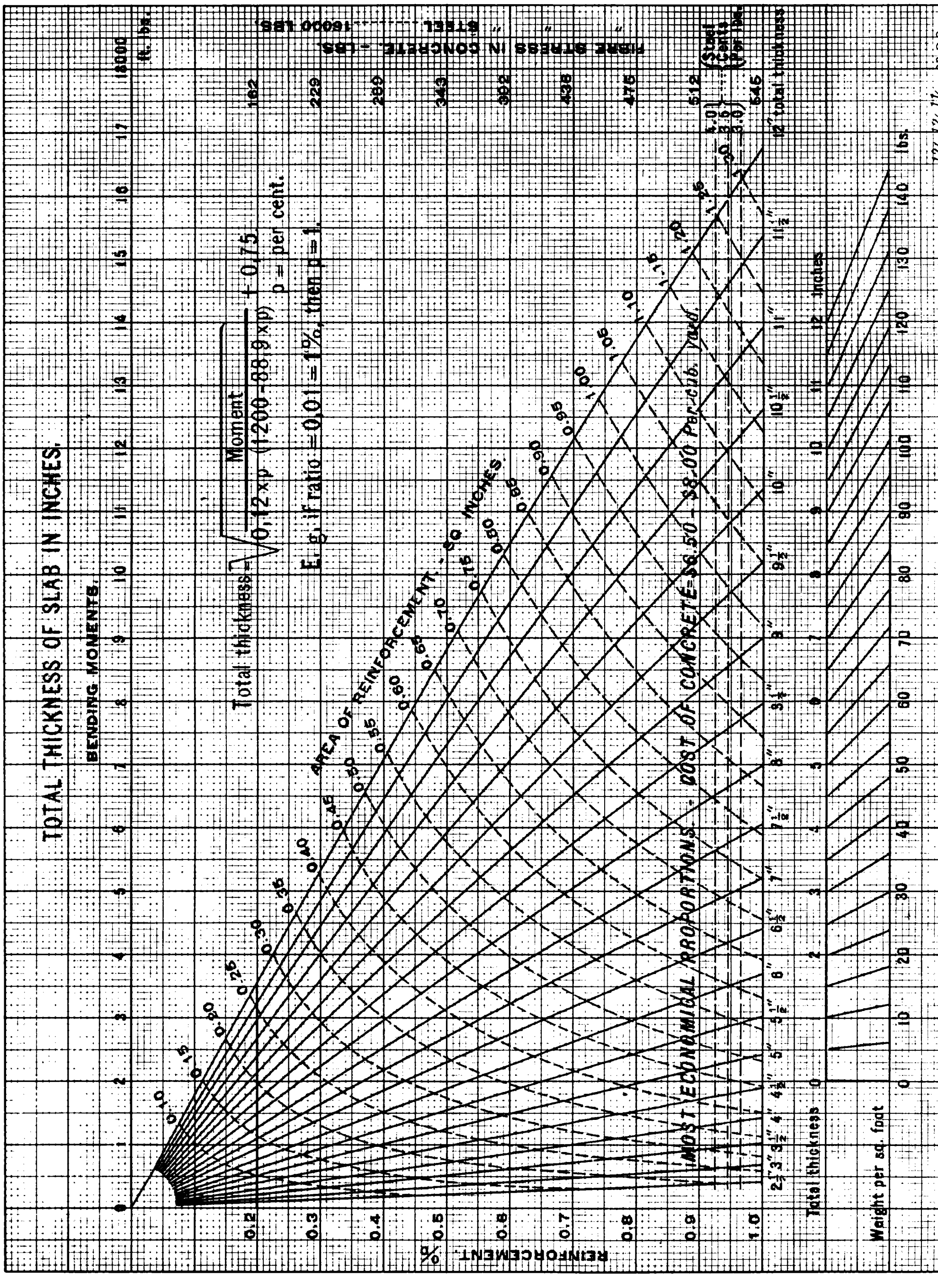

REINFORCED CONCRETE
BENDING MOMENTS FOR SLABS & PANELS.
Bending moment for Slab = 1/10 x L x sp.²
" " Panel = 1/20 x L x sp.²
L = total load per sq. foot,
Sp = span in feet,
Moment corresponding to 12" slab - thickness, and 1% reinforcement
Moment corresponding to 12" panel - thickness, and 1% reinforcement
See diagrams 2 and 5
TOTAL LOAD - LBS.
BENDING MOMENT = FT. LBS. FOR SLABS
" " = " " " PANELS
SPAN

Diagram No. 1


TOTAL THICKNESS OF SLAB IN INCHES.
BENDING MOMENTS.
ft. lbs.
Total thickness = $\sqrt{\dfrac{\text{Moment}}{0.12 \times p\ (1200 - 88.9 \times p)}} + 0.75$
p = per cent.
E. g. if ratio = 0.01 = 1%, then p = 1.
AREA OF REINFORCEMENT - SQ. INCHES.
MOST ECONOMICAL PROPORTIONS - COST OF CONCRETE = $6.50 - $8.00 Per cub. yard.
FIBRE STRESS IN CONCRETE - LBS.
STEEL 16000 LBS.
REINFORCEMENT %
Total thickness
Inches
Weight per sq. foot
lbs.

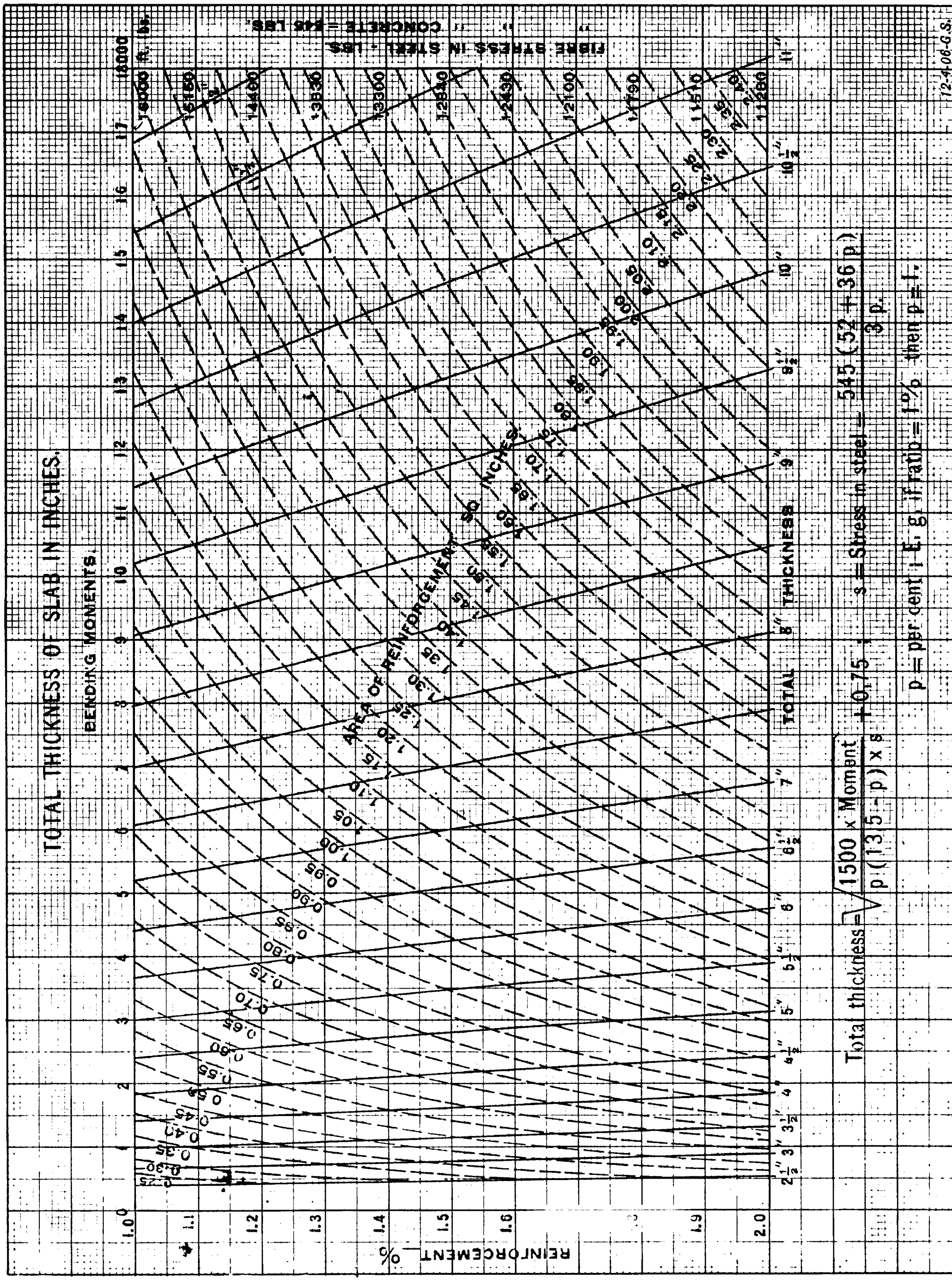

TOTAL THICKNESS OF SLAB IN INCHES.
BENDING MOMENTS.
18000 ft. lbs.
FIBRE STRESS IN STEEL - LBS.
CONCRETE = 545 LBS.
AREA OF REINFORCEMENT SQ. INCHES.
TOTAL THICKNESS
REINFORCEMENT %
Total thickness = $\sqrt{\frac{1500 \times \text{Moment}}{p(13.5 - p) \times s}} + 0.75$; s = Stress in steel = $\frac{545 (52 + 36 p)}{3 p}$
p = per cent ; E. g. if ratio = 1%, then p = 1.
12-4-06-G.S.

Diagram No. 3

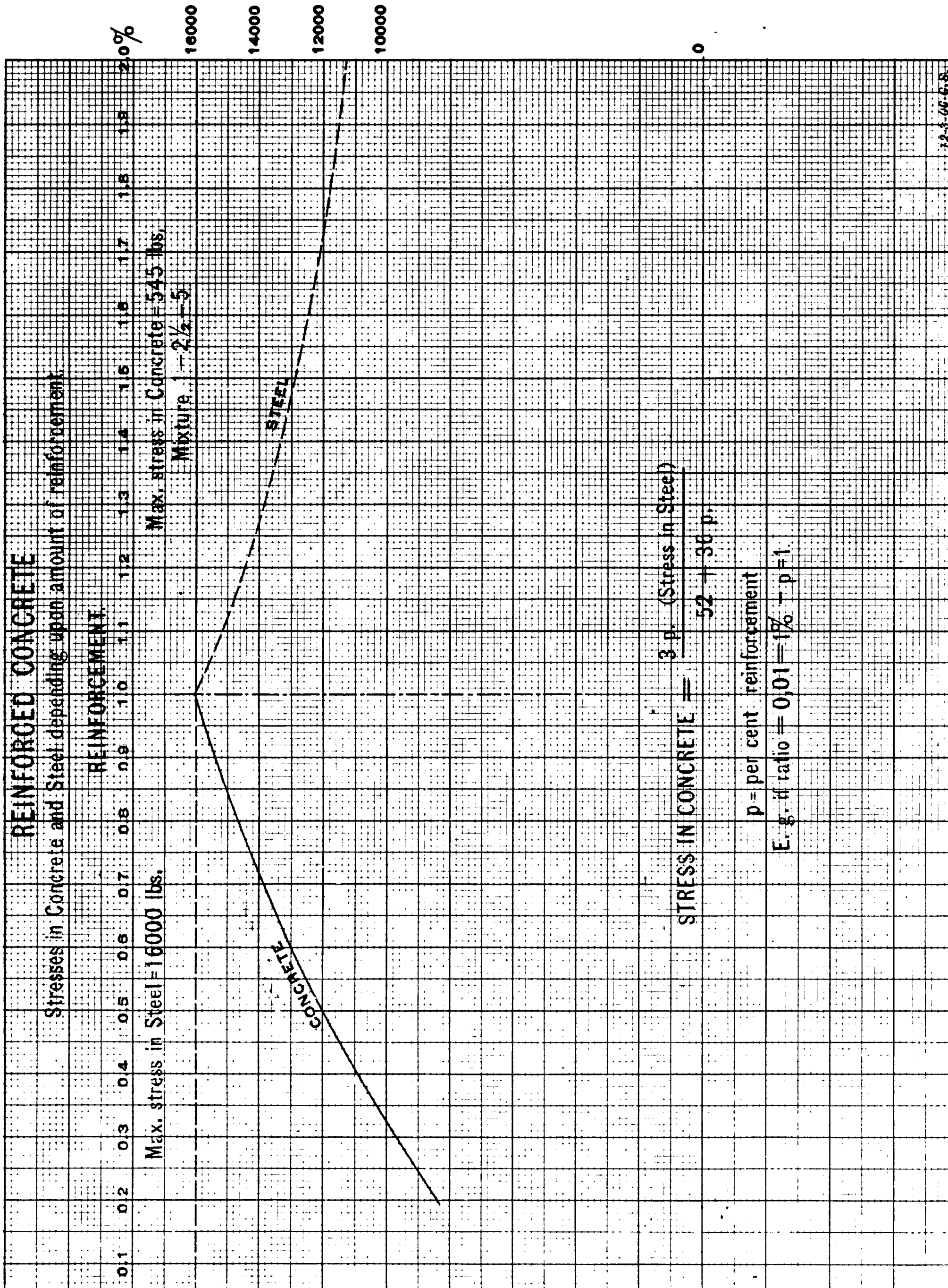

REINFORCED CONCRETE
Stresses in Concrete and Steel depending upon amount of reinforcement.
REINFORCEMENT.
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0%
Max. stress in Steel=16000 lbs.
Max. stress in Concrete=545 lbs.
Mixture 1 — 2½ — 5
16000 14000 12000 10000 0
545 500 400 300 200 100 0
STEEL
CONCRETE
STRESS IN CONCRETE = 3 p. (Stress in Steel) / 52 + 36 p.
p = per cent reinforcement
E. g. if ratio = 0,01 = 1% — p = 1.

Diagram No. 4

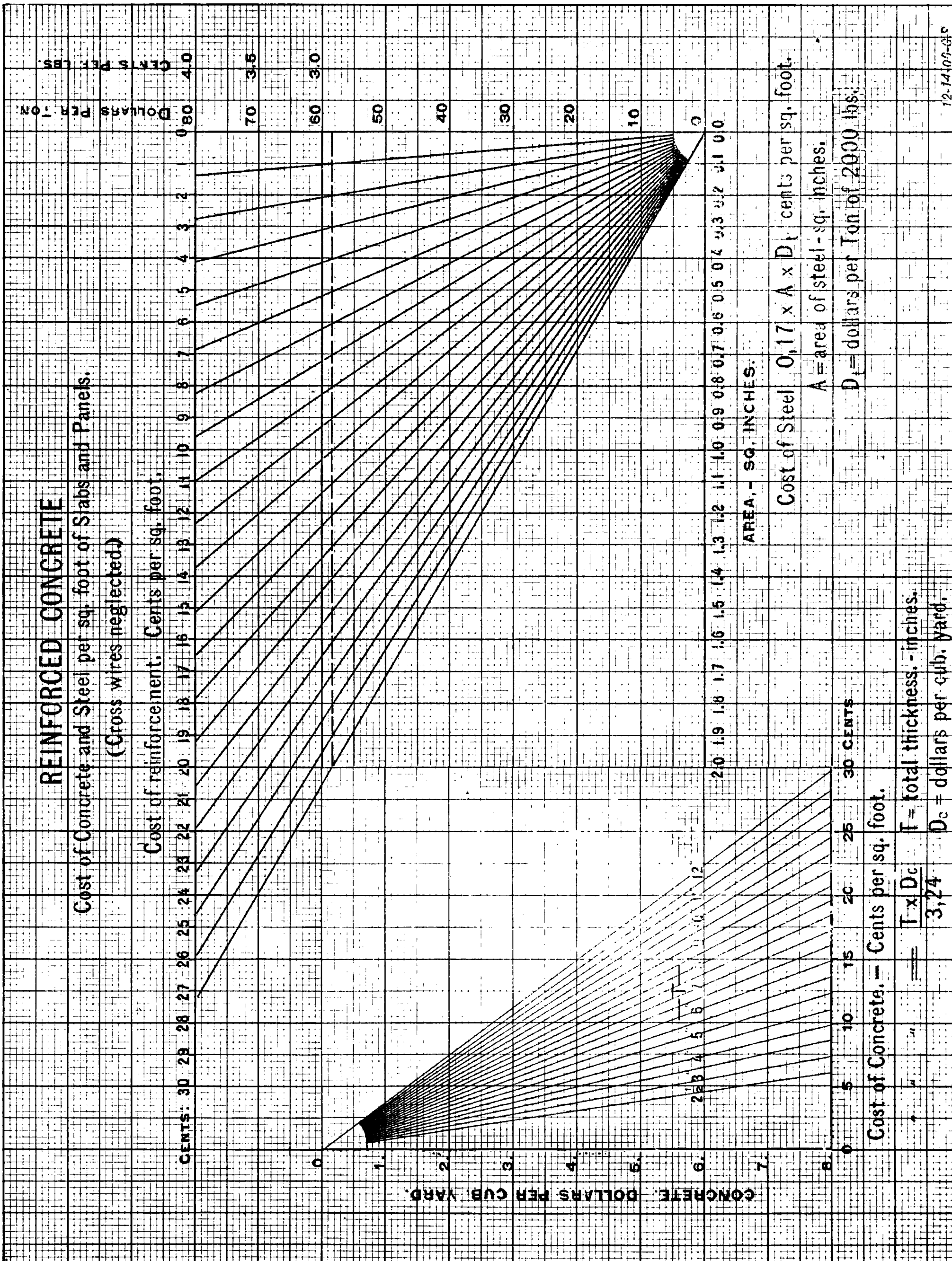

REINFORCED CONCRETE
Cost of Concrete and Steel per sq. foot of Slabs and Panels.
(Cross wires neglected.)
Cost of reinforcement. Cents per sq. foot.
CENTS PER LBS.
DOLLARS PER TON.
AREA.—SQ. INCHES.
Cost of Steel $0.17 \times A \times D_t$ cents per sq. foot.
A = area of steel - sq. inches.
D_t = dollars per Ton of 2000 lbs.
Cost of Concrete.—Cents per sq. foot.
$= \frac{T \times D_c}{3.24}$
T = total thickness. - inches.
D_c = dollars per cub. yard.
CONCRETE. DOLLARS PER CUB. YARD.
30 CENTS
12-14-05-GS

Diagram No. 5

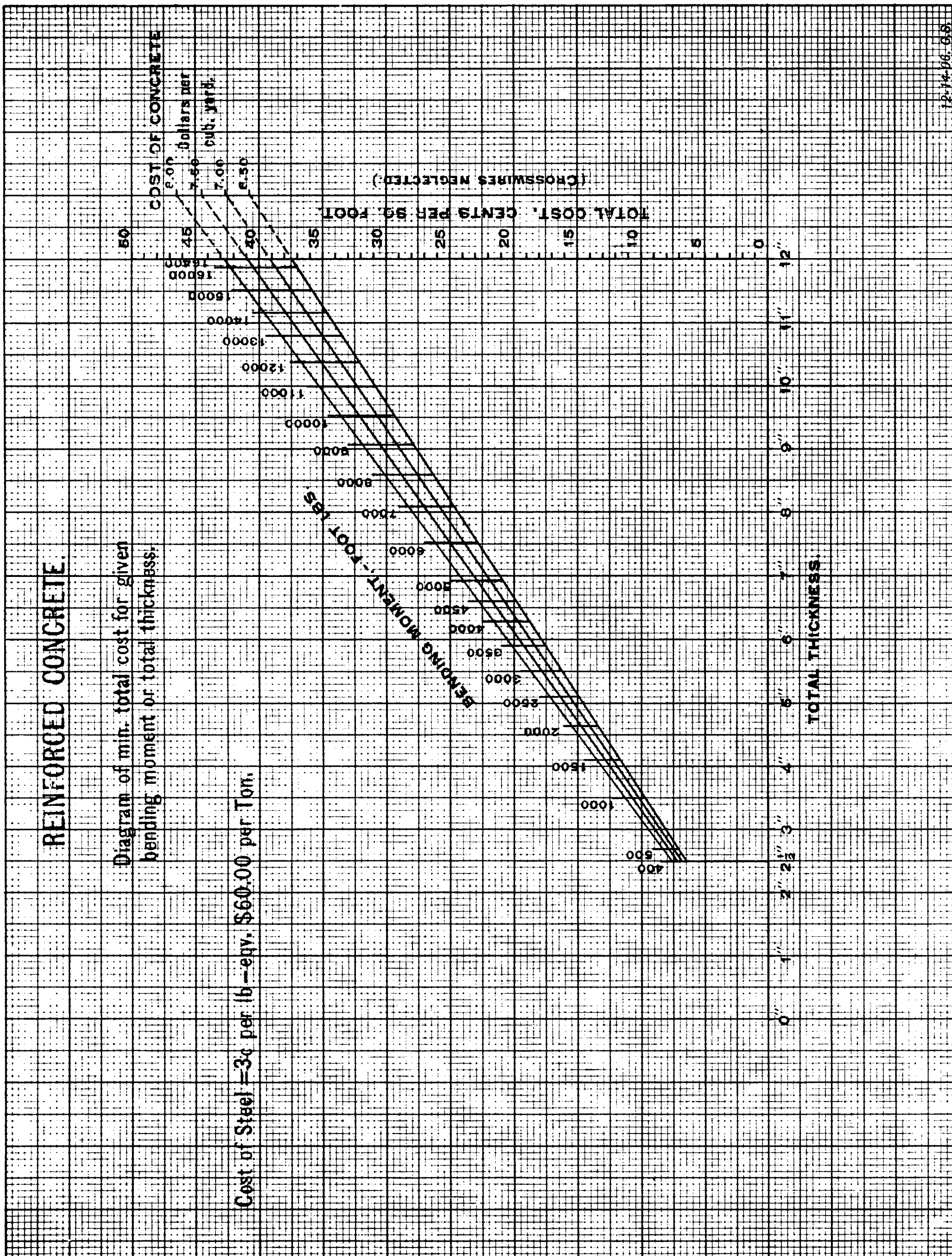

REINFORCED CONCRETE.
Diagram of min. total cost for given bending moment or total thickness.
Cost of Steel =3¢ per lb—eqv. $60.00 per Ton.
COST OF CONCRETE Dollars per cub. yard.
8.00
7.50
7.00
6.50
TOTAL COST, CENTS PER SQ. FOOT.
(CROSSWIRES NEGLECTED.)
50 45 40 35 30 25 20 15 10 5 0
BENDING MOMENT—FOOT LBS
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
400
TOTAL THICKNESS.
0" 1" 2" 2½" 3" 4" 5" 6" 7" 8" 9" 10" 11" 12"
12-14-06. G.S.

Diagram No. 6

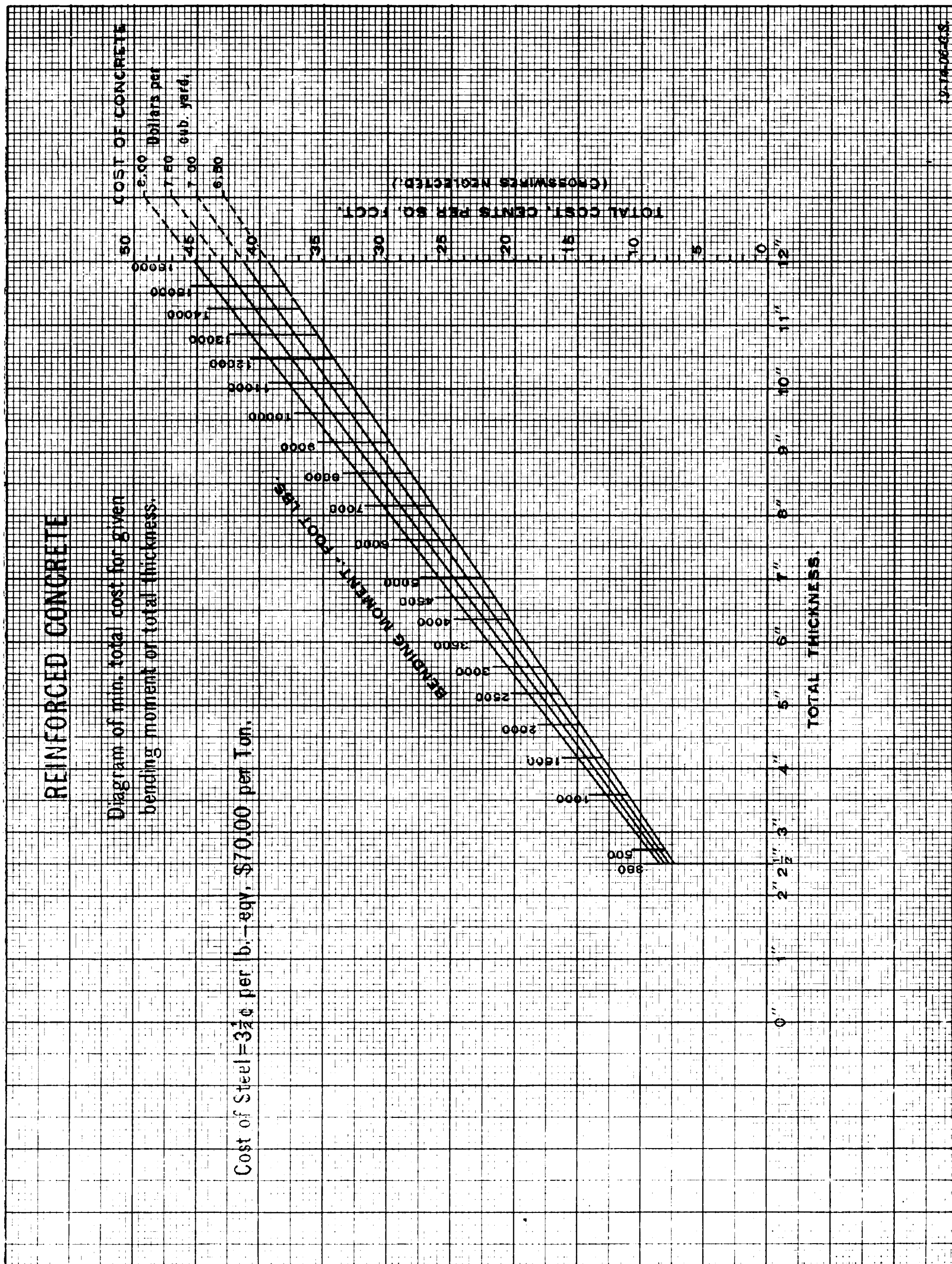

REINFORCED CONCRETE
Diagram of min. total cost for given bending moment or total thickness.
Cost of Steel = 3½c per lb. — eqv. $70.00 per Ton.
COST OF CONCRETE
Dollars per cub. yard.
TOTAL COST, CENTS PER SQ. FOOT.
(CROSSWIRES NEGLECTED.)
BENDING MOMENT, FOOT LBS.
TOTAL THICKNESS.

Diagram No. 7

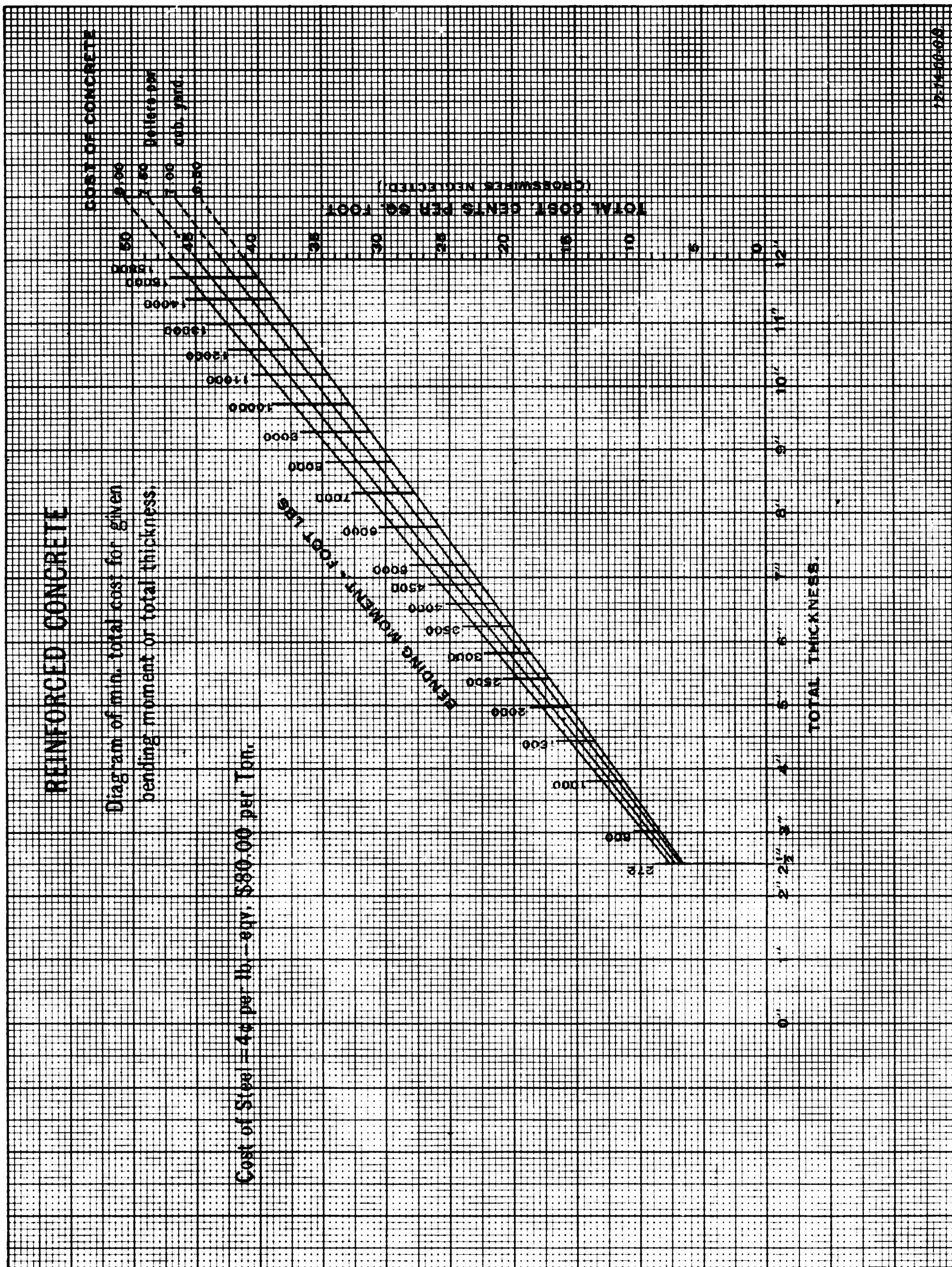

REINFORCED CONCRETE
Diagram of min. total cost for given bending moment or total thickness.
Cost of Steel = 4¢ per lb. — eqv. $80.00 per Ton.
COST OF CONCRETE
Dollars per cub. yard.
TOTAL COST, CENTS PER SQ. FOOT
(CROSSWIRES NEGLECTED)
BENDING MOMENT — FOOT LBS.
TOTAL THICKNESS

Diagram No. 8

AMERICAN STEEL & WIRE CO.'S STEEL AND IRON WIRE GAUGE AND DIFFERENT SIZES OF WIRE

No. of Gauge.	Diameters.			Sectional Area (square inches).	Weight.		Length (feet per pound.)
	Fractions of inch.	Decimals of inch.	Millimeters.		Pounds per foot.	Pounds per mile.	
....	1–2	.5000	12.70	.19635	.6668	3521.	1.500
0000000	....	.4900	12.45	.18857	.6404	3381.	1.562
....	15–32	.46875	11.91	.17257	.5861	3094.	1.706
000000	....	.4615	11.72	.16728	.5681	2999.	1.76
....	7–16	.4375	11.11	.15033	.5105	2696.	1.959
00000	....	.4305	10.93	.14556	.4943	2610.	2.023
....	13–32	.40625	10.32	.12962	.4402	2324.	2.272
0000	....	3938	10.00	.12180	.4136	2184.	2.418
....	3–8	.3750	9.525	.11045	.3751	1980.	2.666
000	....	.3625	9.2075	.10321	.3505	1851.	2.853
....	11–32	.34375	8 731	.092806	.3152	1664.	3.173
00	....	.3310	8.407	.086049	.2922	1543.	3.422
....	5–16	.3125	7.938	.076699	.2605	1375.	3.839
0	....	.3065	7.785	.073782	.2506	1323.	3.991
1	....	.2830	7.188	.062902	.2136	1128.	4.681
....	9–32	.28125	7.144	.062126	.2110	1114.	4.74
2	....	.2625	6.668	.054119	.1838	970.4	5.441
....	1–4	.2500	6.350	.049087	.1667	880.2	5.999
3	....	.2437	6.190	.046645	.1584	836.4	6.313
4	....	.2253	5.723	.039867	.1354	714.8	7.386
....	7–32	.21875	5.556	.037583	.1276	673.9	7.835
5	....	.2070	5.258	.033654	.1143	603.4	8.750
6	....	.1920	4.877	.028953	.09832	519.2	10.17
....	3–16	.1875	4.763	.027612	.09377	495.1	10.66
7	....	.1770	4.496	.024606	.08356	441.2	11.97
8	....	.1620	4.115	.020612	.07000	369.6	14.29
....	5–32	.15625	3.969	.019175	.06512	343.8	15.36
9	....	.1483	3.767	.017273	.05866	309.7	17.05
10	....	.1350	3.429	.014314	.04861	256.7	20.57
....	1–8	.125	3.175	.012272	.04168	220.0	24.00
11	....	.1205	3.061	.011404	.03873	204.5	25.82
12	....	.1055	2.68	.0087417	.02969	156.7	33.69
....	3–32	.09375	2.381	.0069029	.02344	123.8	42 66
13	....	.0915	2.324	.0065755	.02233	117.9	44 78
14	....	.0800	2.032	.0050266	.01707	90.13	58.58
15	....	.0720	1.829	.0040715	.01383	73.01	72.32

AMERICAN STEEL & WIRE CO.'S STEEL AND IRON WIRE GAUGE AND DIFFERENT SIZES OF WIRE—Continued

No. of Gauge.	Diameters.			Sectional Area (square inches.)	Weight.		Length.
	Fractions of inch.	Decimals of inch.	Millimeters.		Pounds per foot.	Pounds per mile.	(feet per pound.)
16	1–16	.0625	1.588	.0030680	.01042	55.01	95.98
17	....	.0540	1.372	.0022902	.007778	41.07	128.60
18	....	.0475	1.207	.0017721	.006018	31.77	166.20
19	....	.0410	1.041	.0013203	.004484	23.67	223.00
20	....	.0348	.8839	.00095115	.003230	17.05	309.60
21	....	.0317	.8052	.00078924	.002680	14.15	373.10
..	1–32	.03125	.7938	.00076699	.002605	13.75	383.90
22	....	.0286	.7264	.00064242	.002182	11.52	458.4
23	....	.0258	.6553	.00052279	.001775	9.374	563.3
24	....	.0230	.5842	.00041548	.001411	7.45	708.7
25	....	.0204	.5182	.00032685	.001110	5.861	900.9
26	....	.0181	.4597	.00025730	.0008738	4.614	1144.
27	....	.0173	.4394	.00023506	.0007983	4.215	1253.
28	....	.0162	.4115	.00020612	.0007000	3.696	1429.
29	....	.0150	.3810	.00017671	.0006001	3.169	1666.
30	....	.0140	.3556	.00015394	.0005228	2.760	1913.
31	....	.0132	.3353	.00013685	.0004647	2.454	2152.
32	....	.0128	.3251	.00012868	.0004370	2.307	2288.
33	....	.0118	.2997	.00010936	.0003714	1.961	2693.
34	....	.0104	.2642	.000084949	.0002885	1.523	3466.
35	....	.0095	.2413	.000070882	.0002407	1.271	4154.
36	....	.0090	.2286	.000063617	.0002160	1.141	4629.
37	....	.0085	.2159	.000056745	.0001927	1.017	5189.
38	....	.0080	.2032	.000050266	.0001707	.9013	5858.
39	....	.0075	.1905	.000044179	.0001500	.7922	6665.
40	....	.0070	.1778	.000038485	.0001307	.6901	7652.
41	....	.0066	.1676	.000034212	.0001162	.6134	8607.
42	....	.0062	.1575	.000030191	.0001025	.5413	9753.
43	....	.0060	.1524	.000028274	.00009602	.5070	10415.
44	....	.0058	.1473	.000026421	.00008972	.4737	11145.
45	....	.0055	.1397	.000023758	.00008068	.4260	12394.
46	....	.0052	.1321	.000021237	.00007212	.3808	13866.
47	....	.0050	.1270	.000019635	.00006668	.3521	14997.
48	....	.0048	.1219	.000018096	.00006145	.3245	16273.
49	....	.0046	.1168	.000016619	.00005644	.2980	17718.
50	....	.0044	.1118	.000015205	.00005164	.2726	19366.

COMPARATIVE SIZES WIRE GAUGE IN DECIMALS OF AN INCH

No of Wire Gauge.	American Steel & Wire Co.	American Standard (B. & S.)	Birmingham or Stubs'.	British Imperial Standard.*	Old English or London.	French.
0000000	.4900	.....	....	.500	.....	....
000000	.4615	.58000	....	.464	.....	....
00000	.4305	.51650	.500	.432	.....	....
0000	.3938	.46000	.454	.400	.4540	....
000	.3625	.40964	.425	.372	.4250	....
00	.3310	.36480	.380	.348	.3800	....
0	.3065	.32486	.340	.324	.3400	....
1	.2830	.28930	.300	.300	.3000	.0325
2	.2625	.25763	.284	.276	.2840	.040
3	.2437	.22942	.259	.252	.2590	.050
4	.2253	.20431	.238	.232	.2380	.0625
5	.2070	.18194	.220	.212	.2200	.068
6	.1920	.16202	.203	.192	.2030	.083
7	.1770	.14428	.180	.176	.1800	.097
8	.1620	.12849	.165	.160	.1650	.110
9	.1483	.11443	.148	.144	.1480	.120
10	.1350	.10189	.134	.128	.1340	.135
11	.1205	.09074	.120	.116	.1200	.149
12	.1055	.08081	.109	.104	.1090	.162
13	.0915	.07196	.095	.092	.0950	.172
14	.0800	.06408	.083	.080	.0830	.185
15	.0720	.05706	.072	.072	.0720	.197
16	.0625	.05082	.065	.064	.0650	.212
17	.0540	.04525	.058	.056	.0580	.225
18	.0475	.04030	.049	.048	.0490	.238
19	.0410	.03589	.042	.040	.0400	.250
20	.0348	.03196	.035	.036	.0350	.263
21	.0317	.02846	.032	.032	.0315	.279
22	.0286	.02535	.028	.028	.0295	.290
23	.0258	.02257	.025	.024	.0270	.303
24	.0230	.02010	.022	.022	.0250	.316
25	.0204	.01790	.020	.020	.0230	.331
26	.0181	.01594	.018	.018	.0205	.342
27	.0173	.01420	.016	.0164	.01875	.356
28	.0162	.01264	.014	.0148	.01650	.371
29	.0150	.01126	.013	.0136	.01550	.383
30	.0140	.01003	.012	.0124	.01375	.394
31	.0132	.00893	.010	.0116	.01225	.408
32	.0128	.00795	.009	.0108	.01125	.419
33	.0118	.00708	.008	.0100	.01025	.431
34	.0104	.00630	.007	.0092	.00950	.448
35	.0095	.00561	.005	.0084	.00900	.458
36	.0090	.00500	.004	.0076	.00750	.472
37	.0085	.00445	....	.0068	.00650	.485
38	.0080	.00396	....	.0060	.00575	.499
39	.0075	.00353	....	.0052	.00500	.509
40	.0070	.00314	....	.0048	.00450	.524

*Also called New British or English Legal Standard.

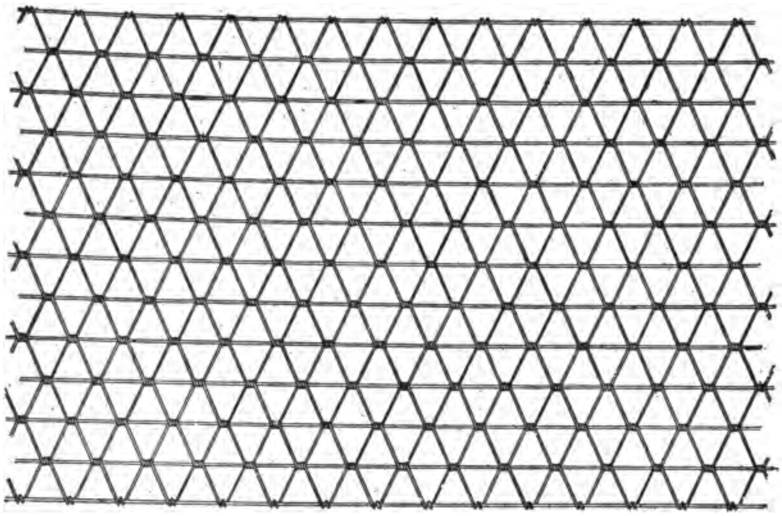
WEIGHTS OF SQUARE AND ROUND STEEL PER LINEAL FOOT.

Weight per lineal foot÷3.4=Sectional area in square inches.

(One Cubic Foot of Steel Weighs 489.6 Pounds.)

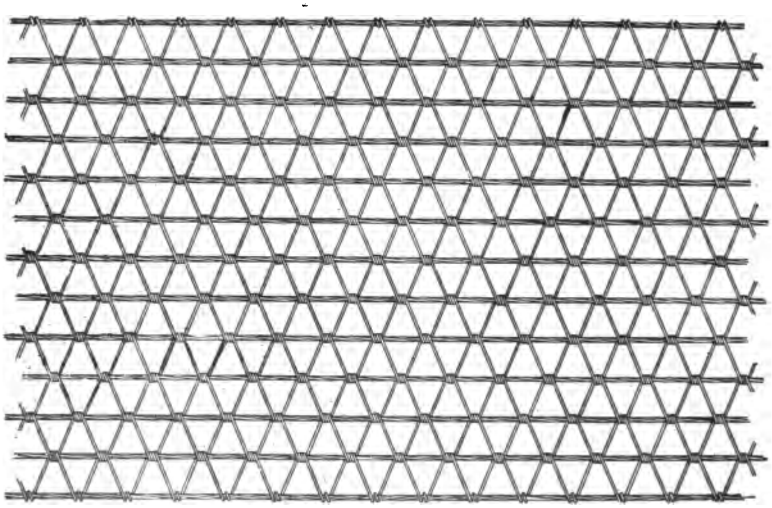
Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.
	□	O		□	O
			2	13.60	10.68
$\frac{1}{16}$	.013	.010	$2\frac{1}{16}$	14.46	11.36
$\frac{1}{8}$	.053	.042	$2\frac{1}{8}$	15.35	12.06
$\frac{3}{16}$	.120	.094	$2\frac{3}{16}$	16.27	12.78
$\frac{1}{4}$	.213	.167	$2\frac{1}{4}$	17.22	13.52
$\frac{5}{16}$	.332	.261	$2\frac{5}{16}$	18.19	14.28
$\frac{3}{8}$	.478	.376	$2\frac{3}{8}$	19.18	15.07
$\frac{7}{16}$	.651	.511	$2\frac{7}{16}$	20.20	15.86
$\frac{1}{2}$	.850	.668	$2\frac{1}{2}$	21.25	16.69
$\frac{9}{16}$	1.076	.845	$2\frac{9}{16}$	22.33	17.53
$\frac{5}{8}$	1.328	1.043	$2\frac{5}{8}$	23.43	18.40
$\frac{11}{16}$	1.607	1.262	$2\frac{11}{16}$	24.56	19.29
$\frac{3}{4}$	1.913	1.502	$2\frac{3}{4}$	25.00	20.20
$\frac{13}{16}$	2.245	1.763	$2\frac{13}{16}$	26.90	21.12
$\frac{7}{8}$	2.603	2.044	$2\frac{7}{8}$	28.10	22.07
$\frac{15}{16}$	2.989	2.347	$2\frac{15}{16}$	29.34	23.04
1	3.400	2.670	3	30.60	24.03
$1\frac{1}{16}$	3.838	3.014	$3\frac{1}{16}$	31.89	25.04
$1\frac{1}{8}$	4.303	3.379	$3\frac{1}{8}$	33.20	26.08
$1\frac{3}{16}$	4.795	3.766	$3\frac{3}{16}$	34.55	27.13
$1\frac{1}{4}$	5.312	4.173	$3\frac{1}{4}$	35.92	28.20
$1\frac{5}{16}$	5.857	4.600	$3\frac{5}{16}$	37.31	29.30
$1\frac{3}{8}$	6.428	5.049	$3\frac{3}{8}$	38.73	30.42
$1\frac{7}{16}$	7.026	5.518	$3\frac{7}{16}$	40.18	31.56
$1\frac{1}{2}$	7.650	6.008	$3\frac{1}{2}$	41.65	32.71
$1\frac{9}{16}$	8.301	6.520	$3\frac{9}{16}$	43.14	33.90
$1\frac{5}{8}$	8.978	7.051	$3\frac{5}{8}$	44.68	35.09
$1\frac{11}{16}$	9.682	7.604	$3\frac{11}{16}$	46.24	36.31
$1\frac{3}{4}$	10.41	8.178	$3\frac{3}{4}$	47.82	37.56
$1\frac{13}{16}$	11.17	8.773	$3\frac{13}{16}$	49.42	38.81
$1\frac{7}{8}$	11.95	9.388	$3\frac{7}{8}$	51.05	40.10
$1\frac{15}{16}$	12.76	10.02	$3\frac{15}{16}$	52.71	41.40

PATENTS APPLIED FOR



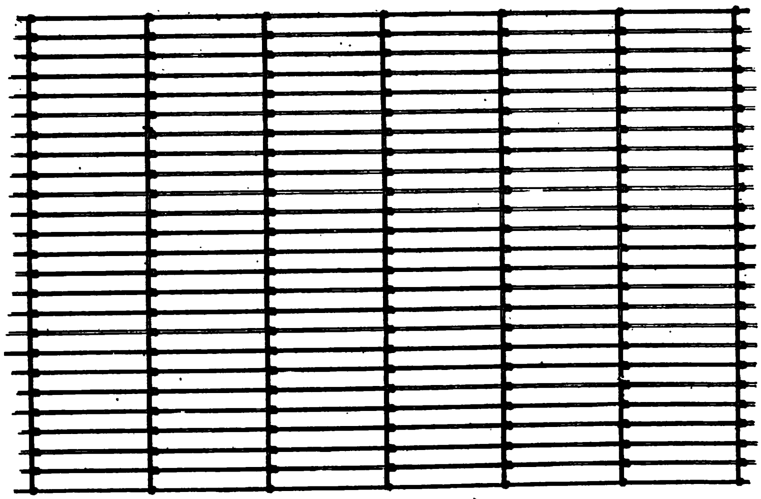
4-inch Triangular Mesh.
Reinforcement Solid Longitudinal.

PATENTS APPLIED FOR.



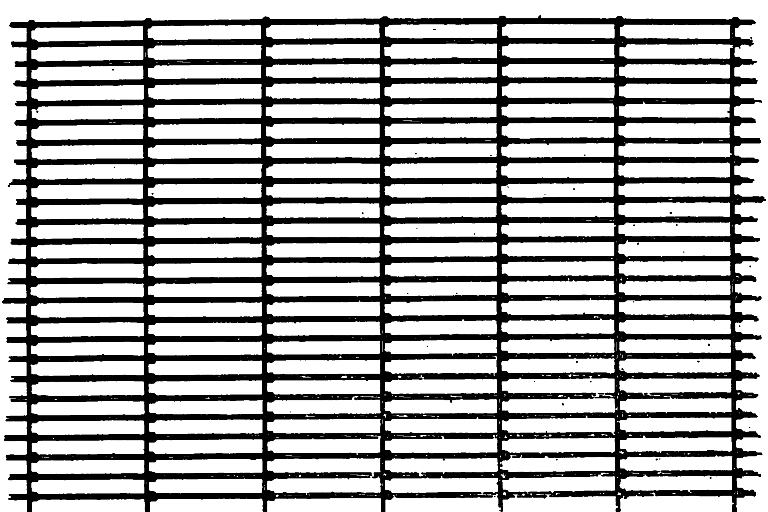
4-inch Triangular Mesh.
Reinforcement Stranded Longitudinals

PATENTS APPLIED FOR.

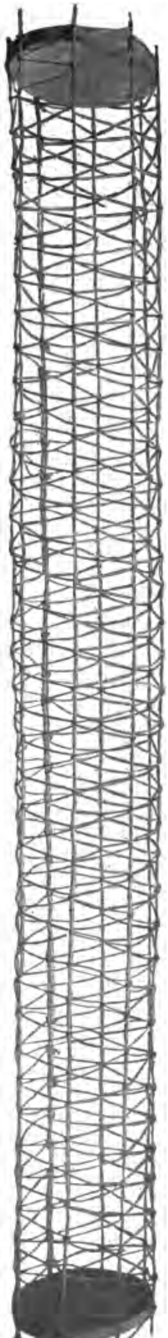


Square Mesh Reinforcemnt.
Solid Longitudinals.

PATENTS APPLIED FOR.



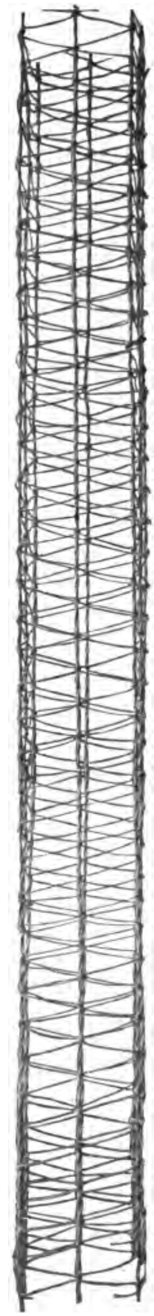
Square Mesh Reinforcement.
Stranded Longitudinals.



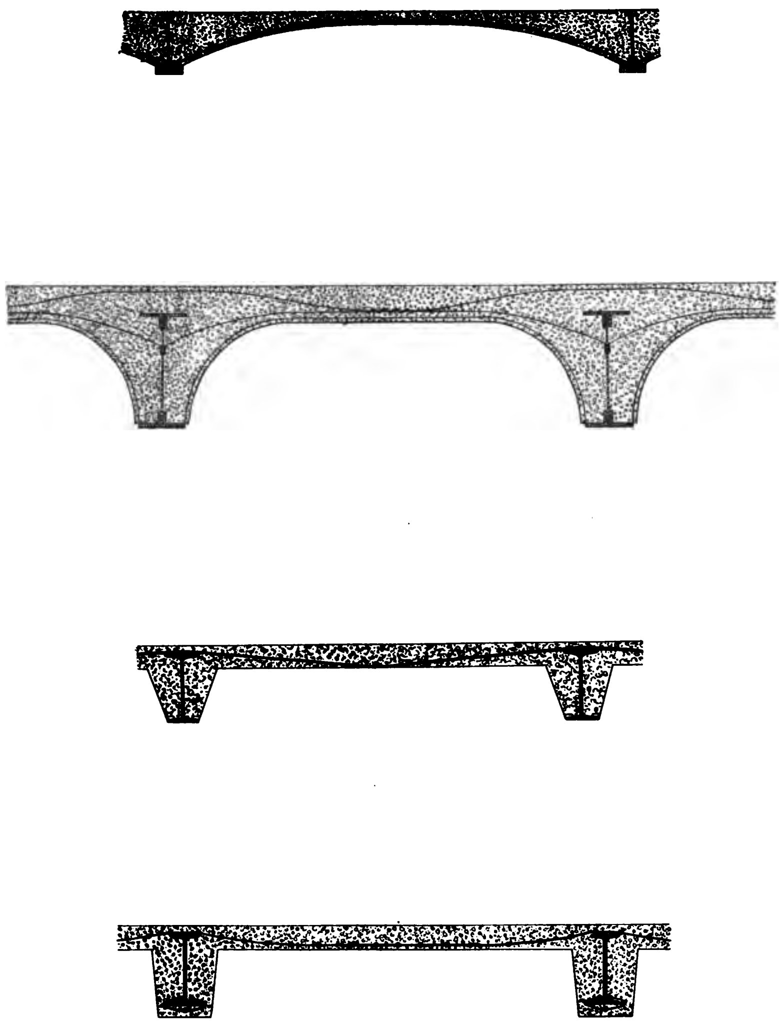
Round Column

TRIANGULAR MESH REINFORCEMENT FOR COLUMNS.

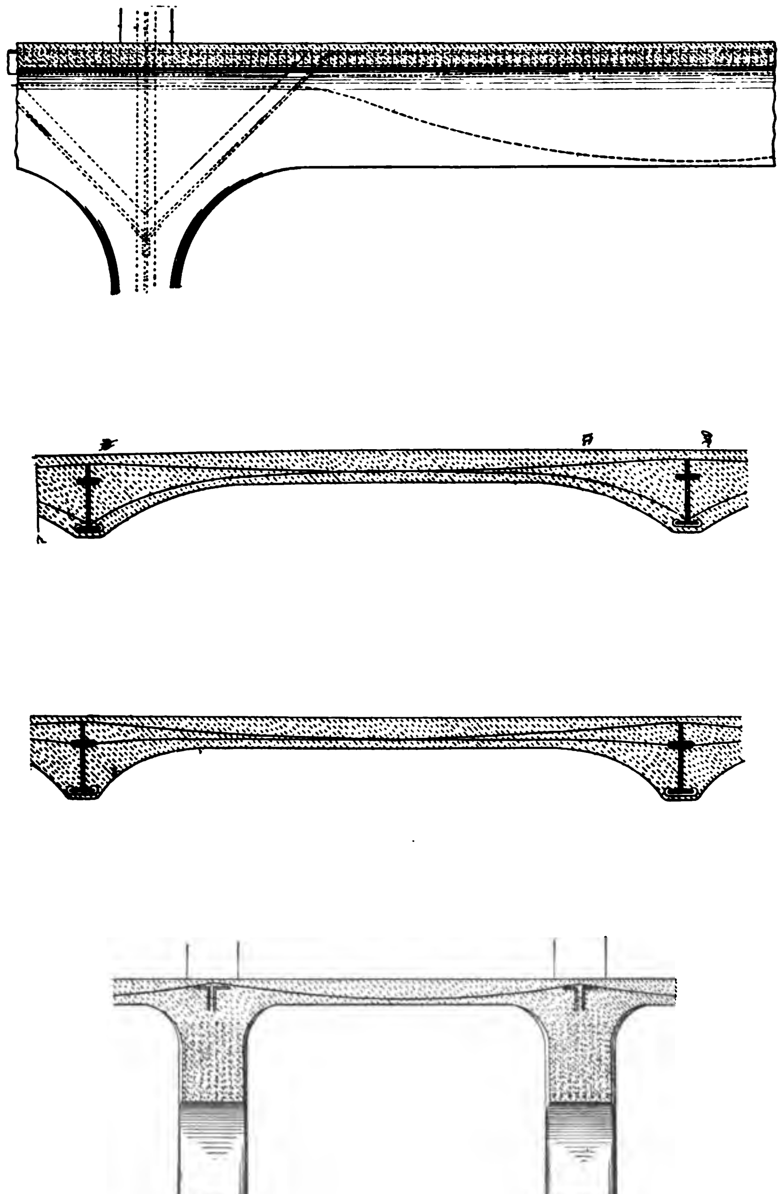
Made with hinged joints on longitudinals, either four or eight inches apart. Can be readily formed into triangular, square, round or irregular shaped cages, without bending the wires. An ideal reinforcement for TELEGRAPH, TELEPHONE or FENCE posts.



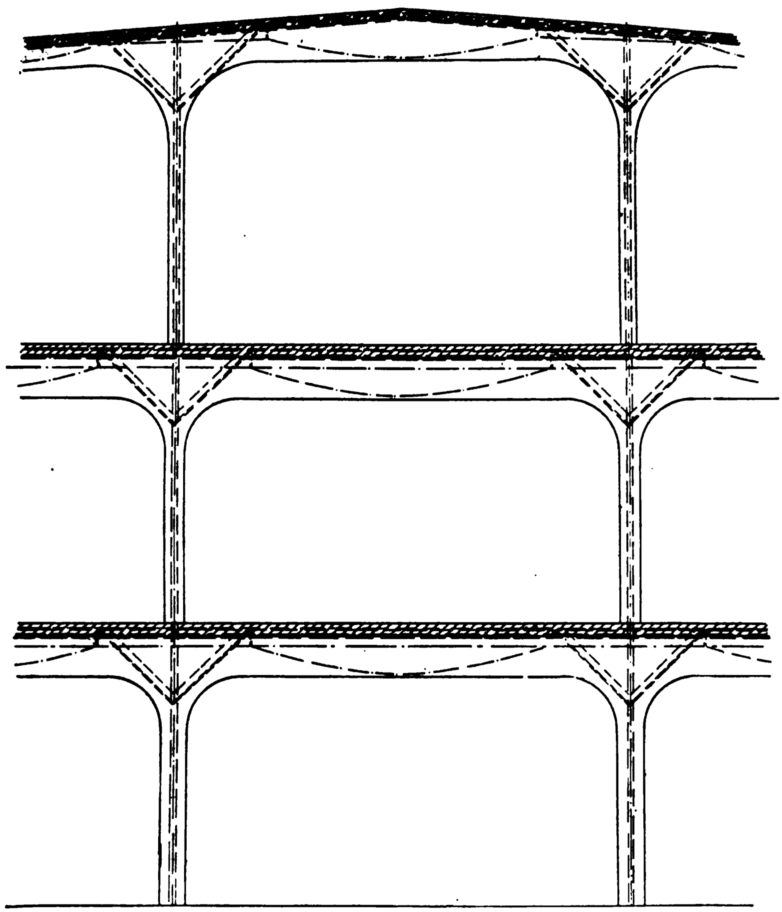
Square Column



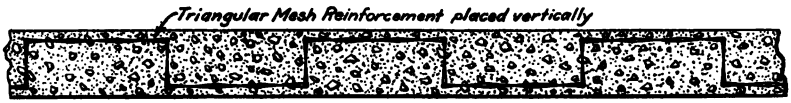
Suggestions for Floor Construction in Reinforced Concrete.



Suggestions for Floor Costruction in Reinforced Concrete.

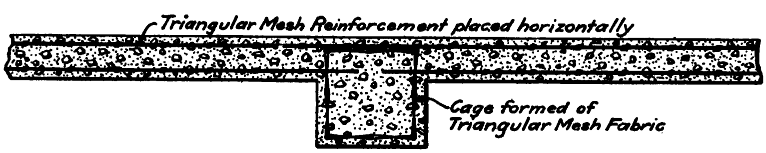


Factory or Mill Construction in Reniforced Concrete.

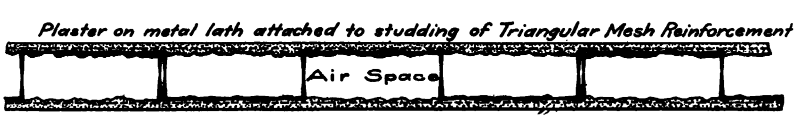


Wall

Wall

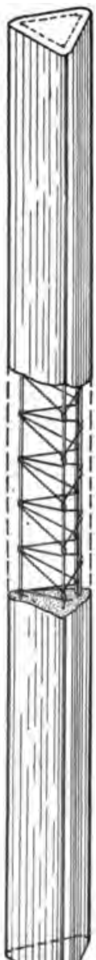


Wall with Pilaster

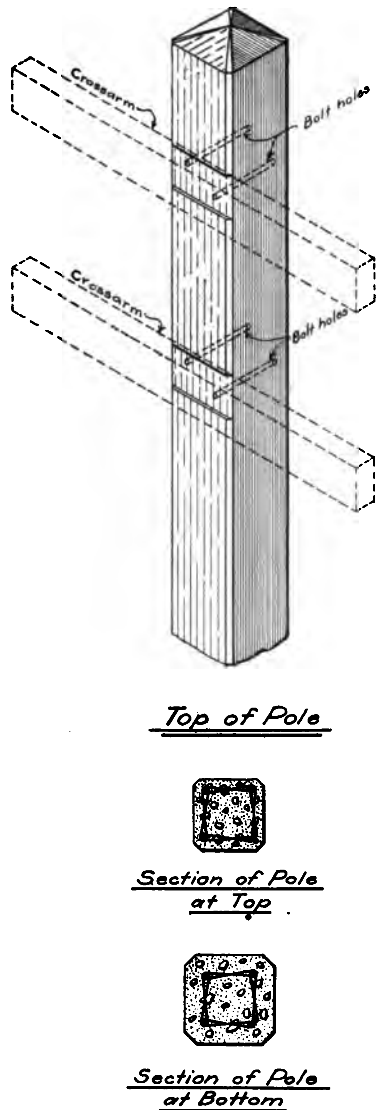


Plaster Partition Wall

Wall Construction

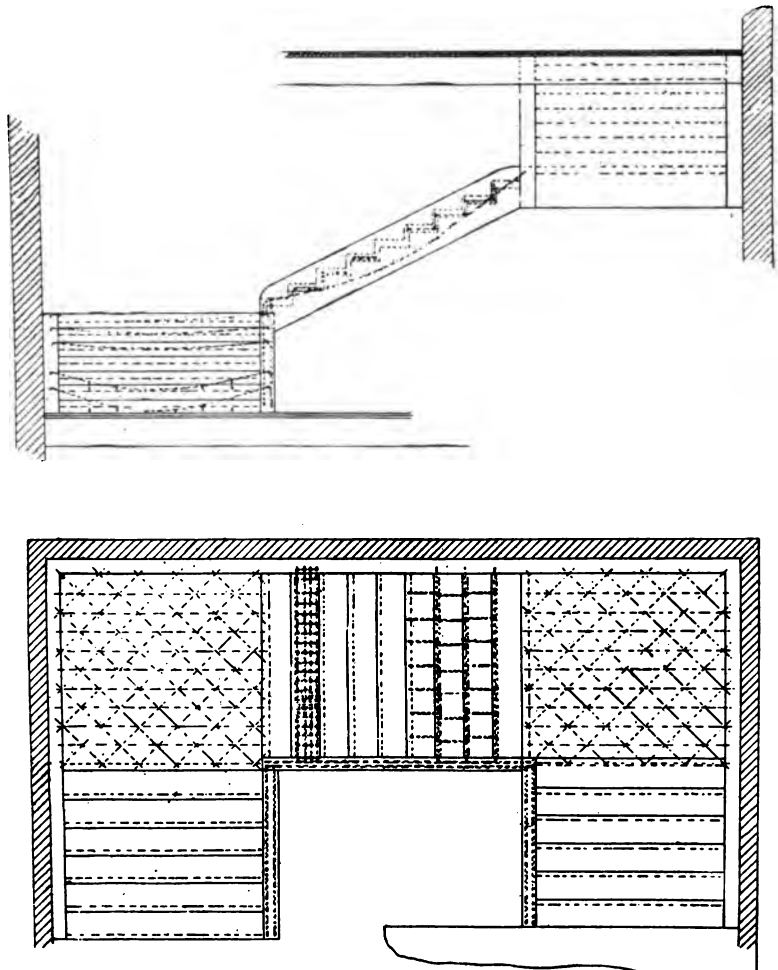


Fence Post

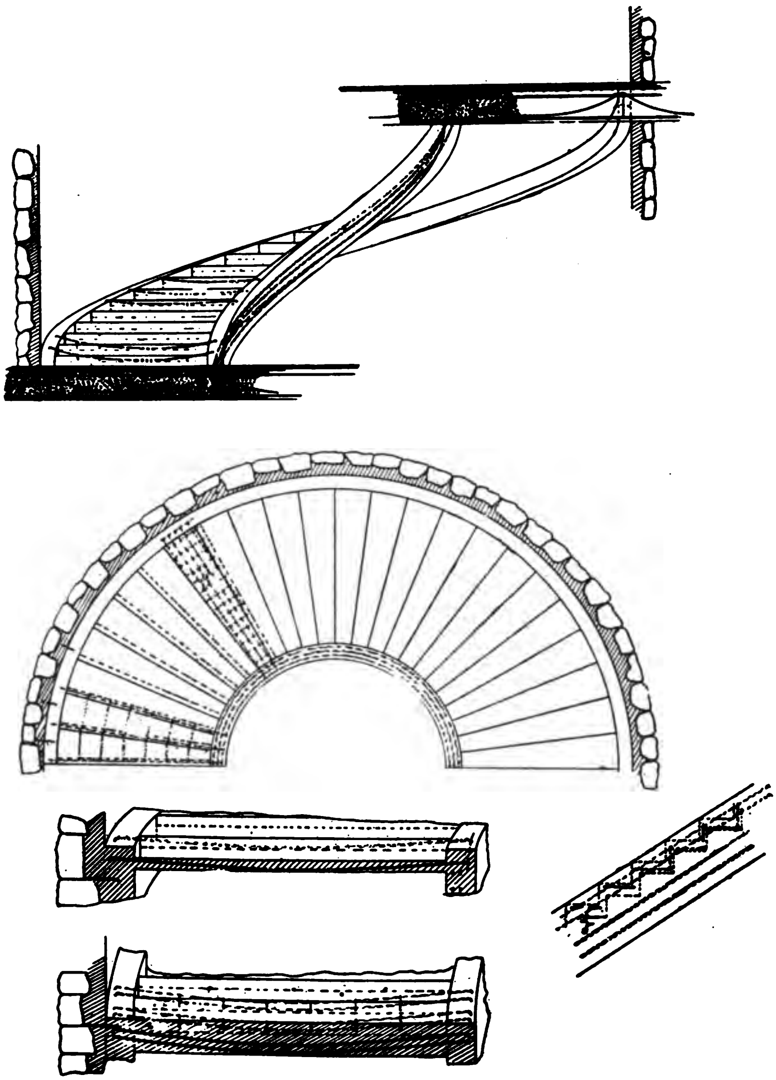


Telegraph Pole

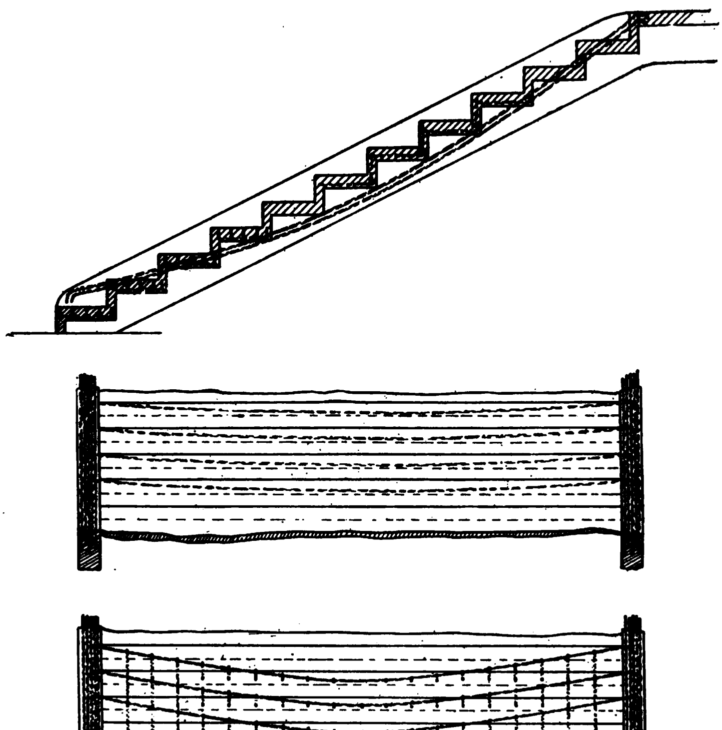
Concrete Reinforced with Triangular 2-inch Mesh Woven Wire.



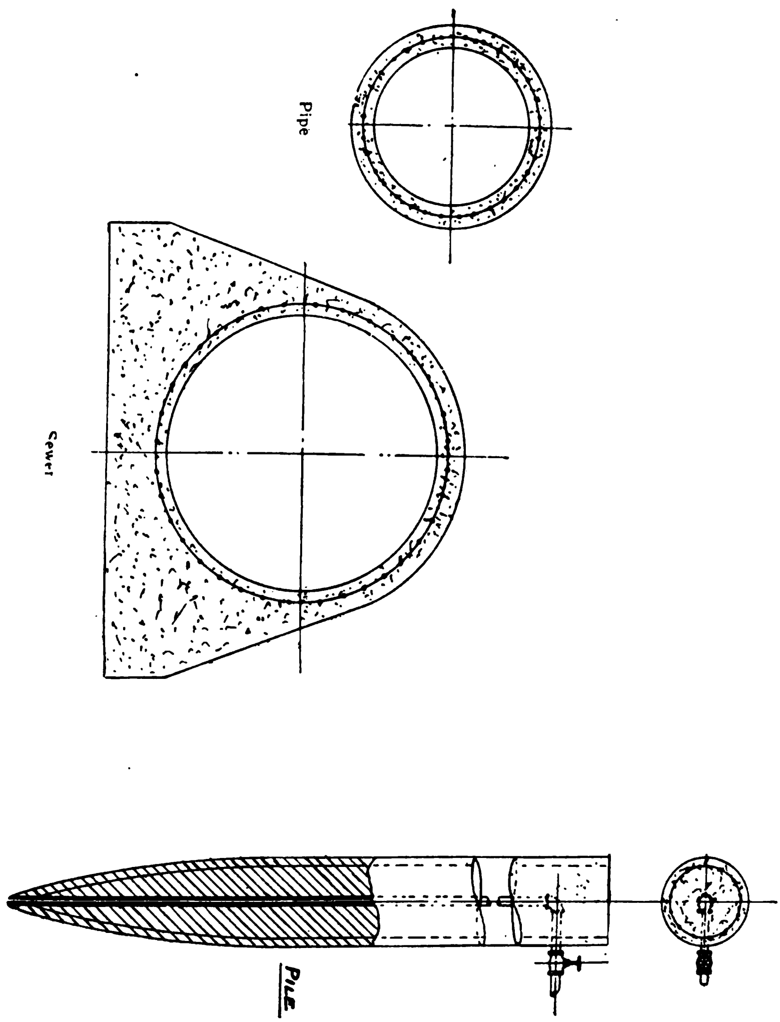
Stair Construction in Reinforced Concrete.



Winding Stairs in Reinforced Concrete.



Reinforced Concrete Stairs.



Suggestions in Reinforced Concrete.

CHAS F. WHITTLESLEY & CO., Architects.

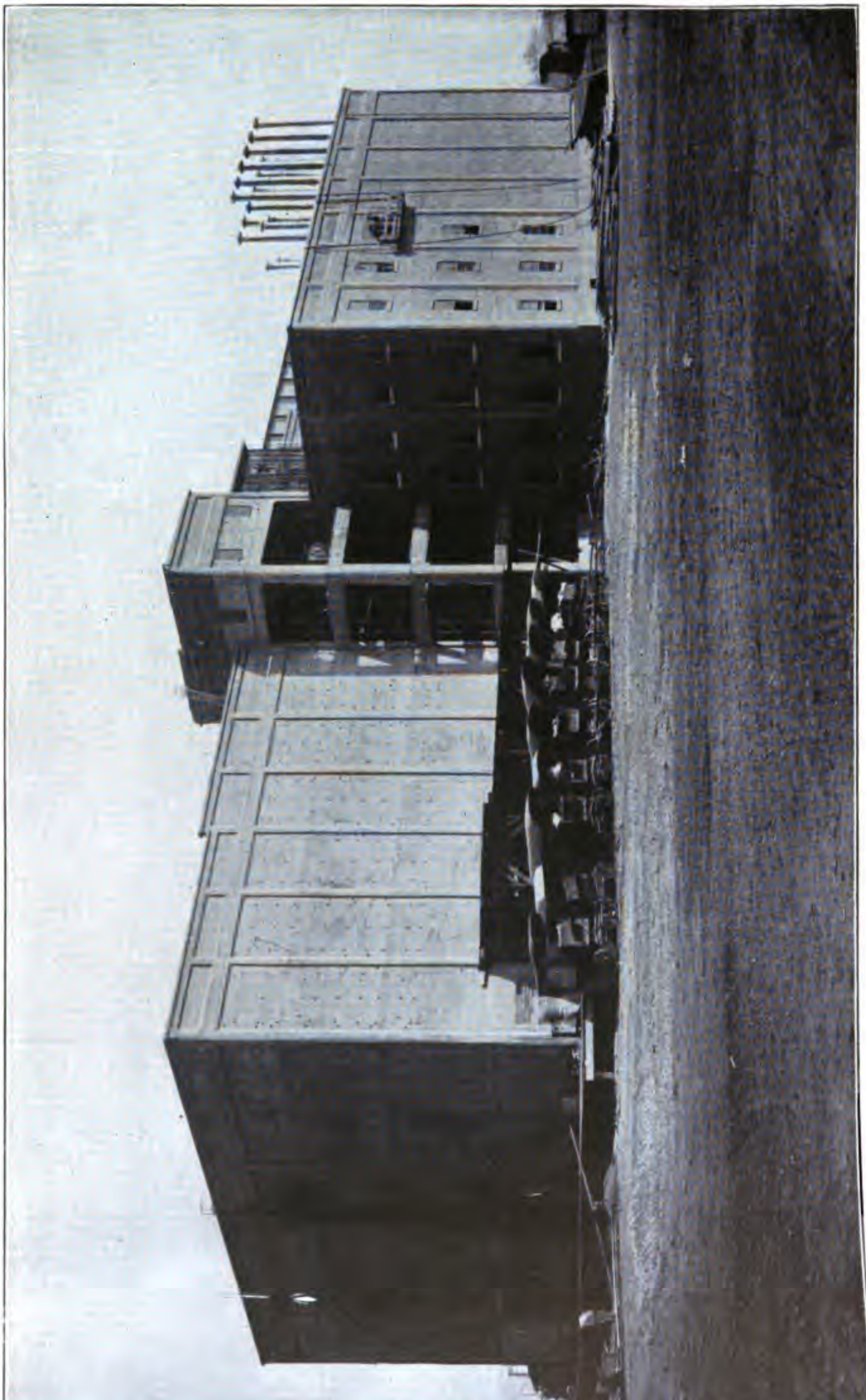
RICHARDS NEUSTADT CONST. CO., Builders.

HOTEL WENTWORTH.
Pasadena, California.
Built entirely of Reinforced Concrete. Triangular Mesh Reinforcement Used Throughout.
Floor Area, Ten Acres.

Hotel Wentworth During Construction, Showing Triangular Mesh Reinforcement.

EAMES & YOUNG,
Architects

ELY WALKER DRY GOODS CO.
St. Louis, Mo.
Triangular Mesh Reinforcement Used in Floors by The National Fire Proofing Co.



Maier Packing Plants, Los Angeles, Cal. Triangular Mesh Reinforcement Used Throughout.

Maier Packing Plant During Construction, Showing Triangular Mesh Reinforcement as Used in Floors.

JOHN PARKINSON, Architect,
Los Angeles.

ALEXANDRIA HOTEL,
Los Angeles, Cal.

Triangular Mesh Reinforcement used in Floors by National Fire Proofing Co.

WHIDDEN & LEWIS,
Architects.

CORBETT BUILDING,
Portland, Oregon.

Triangular Mesh Reinforcement Used in Floors.

Triangular Reinforcement as Used in Floors of Corbett Building.

Copper Insulating Mills, Worcester, Mass.—Concrete Floors with Triangular Mesh Reinforcement.

Copper Insulating Mill at Worcester, Mass.—Showing 2 Layers of No. 8 Triangular Mesh Reinforcement in Floors Before Placing Concrete.

Section of Insulating Mill—Showing Triangular Reinforcement, and Nailing Strips for Top Floor—Strips Laid in Bed of Cement Grouting on Top of Reinforced Floor Slab.

BARNETT, HAYNES & BARNETT,
Architects.

MARQUETTE HOTEL.
St. Louis.
Triangular Reinforcement Used in Floors by National Fire Proofing Co.

RECONSTRUCTION OF TUNNEL UNDER CHICAGO RIVER.
Triangular Mesh Reinforcement Used in Binder Course in New Roofs.

Showing Tunnel Under Chicago River, with Steel Beams to Support New Roof.

RECONSTRUCTION OF TUNNEL UNDER CHICAGO RIVER.
Triangular Mesh Reinforcement Used in Binder Course in New Roofs.

Showing Tunnel Under Chicago River, with Steel Beams to Support New Roof.

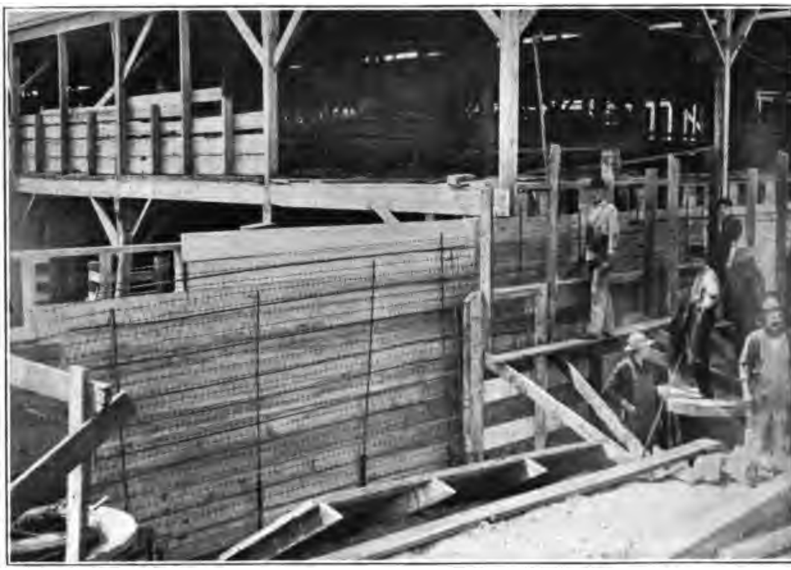
Showing Tringular Mesh and Round Rods used in Concrete Floor Slabs with Hollow Tile.
Built by National Fire Proofing Co.

NORTON BUILDING, Los Angeles, Calif.
Triangular Reinforcement Used with Bars for Long Spans by National Fire Proofing Co.

USED IN COLUMNS AND FLOORS IN MACHINE SHOP.

SECTION OF UNLOADING PENS.

Triangular Reinforcement as used by Union Stock Yards and Transit Co., Chicago.



AS USED IN RETAINING WALLS.

COMPLETED PORTION OF PLATFORM AND PENS.

Triangular Reinforcement as used by Union Stock Yards and Transit Co., Chicago.

TRIANGULAR REINFORCED CONCRETE WATER TROUGHS.

TRIANGULAR REINFORCEMENT AS USED IN FENCE BETWEEN STOCK PENS.

Triangular Reinforcement as used by Union Stock Yards and Transit Co., Chicago.

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